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Agriculture Development Fund

FINAL REPORT

EVALUATION OF THREE PIT ADDITIVES FOR SWINE MANURE ODOR CONTROL AND HANDLING EASE

19970323

Funded by
The Agriculture Development Fund
August 2000

Prepared by: Prairie Swine Centre Inc.

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19970323

101-00140/

FINAL REPORT

July 15th, 2000

on the project entitled:

Evaluation of three pit additives for swine manure odour control and handling ease

Project 97000323
Res. 88BV

submitted to:

Saskatchewan Department of Agriculture and Food

by:

Stéphane P. Lemay, P. Eng., Ph.D.
Research Scientist - Engineering
Prairie Swine Centre Inc.
Saskatoon

SUMMARY

The effectiveness of three pit additives (American BioCatalysts, Pit Boss and Westbridge (H4-5O2)) was evaluated during two trials. Trial (1) consisted of indoor and outdoor phases and Trial (2) had only an indoor phase. Results from the two indoor phases were combined to provide eight replicates. The protocol developed possesses different strengths, including commercial scale layout and evaluation, and increased repetitions. Overall, the performances of the additives were quite mixed. Odour threshold reductions ranged from 0 to 11% reduction during the indoor phase and 0 to 66% reduction during the outdoor phase. Hydrogen sulphide concentrations were reduced from 57 to 76% and ammonia concentrations were reduced by 5 to 33%. All of the additives seemed unable to achieve much solids reduction or solubilization during the indoor phase of the experiment. During the indoor phases, nitrogen content and availability was increased from 7 to 19% and 9 to 25% respectively. Similarly, phosphorous availability was improved from 16 to 24%. The additives did not perform very well in reducing chemical oxygen demand (COD), providing no reduction or a minor reduction during the indoor phase. In general, the additives provided some benefits but were not able to improve all the manure parameters studied.

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Background

Odour control is a primary concern of the swine industry. In some cases, public perception of odour as a nuisance has given swine production a bad reputation. To remedy this perception, efforts have focused on controlling odour at various stages of production. These efforts aim at suppressing odour production in the swine building, however odour nuisance can still become a problem at a later point during storage. To complicate the issue, producers' attempts to locate new operations or expand their existing facilities have been blocked by legal action based on odour complaints. In these cases, opponents are generally neighbours or nearby communities that have heard about or experienced odour nuisance. Publicity from such cases has been costly to producers both socially and economically. For this reason, companies have developed manure pit additives that are intended to control odour. If the additives are effective, they would be of great benefit to the swine industry, easing some of the controversy surrounding the odour issue.

In addition to odour, other issues regarding manure are also becoming more of a concern. These other issues include manure handling ease, manure pit gas production, nutrient retention and waste strength. Manure pit additive manufacturers claim to address these concerns by reducing and solubilizing solids content, suppressing pit gas production, conserving nutrients and reducing waste strength. In the worst case scenario, for any single treatment to be adequate, the additive would need to improve most or all of these characteristics and apply to all stages of manure management. However, improvements in any one of these stages may be all that is required depending on the circumstances at any individual production site.

Past studies have indicated that some progress has been realized with the application of manure pit additives. In a study conducted by Zhu et al. (1997) five additives tested (MPC, Bio-Safe, Shac, X-Stink and CPPD) reduced odour concentration by 58 to 87%, as determined through dynamic triangle forced-choice olfactometry. In the same experiment, only MPC was capable of producing a significant total solids (TS) reduction and Bio-Safe produced significant increases in ammonium-nitrogen (NH_4-N) levels. Lorimer (1996) also reported on results from the experiments conducted by Zhu and Bundy, which indicated that none of the additives reduced TS significantly, but some were observed to promote elevated NH_4-N levels. In another experiment, eight products (Bio Charge, Roebic Deod, Pit Boss, Shac, Bio-409, MS-4, Pit Stop and Deo Odorase) were evaluated in full-scale rooms, resulting in odour reductions of 5 to 48% and ammonia (NH_3) reductions of 42 to 51% (AURI 1997). The AURI study also indicated that the additives produced significant increases in phosphorus (P) relative to control and small increases in NH_4-N. Two of the five additives (NX23 and BioSuper) tested by Martinez et al. (1997) reduced NH_3 emissions by 40 to 50%. Heber et al. (1997) reported reductions of NH_3 emissions from 1.8 to 5.9 g/day-pig and small decreases in overall NH_3, hydrogen sulphide (H_2S) and carbon dioxide (CO_2) concentrations. Out of the seven additives (Agri-Scents, Biosurge, Hydrogen cyanamide, Micro-Aid, Natural Odor Catalyst, Sphagnum peat and Roebic) evaluated by Patni and Jui (1993), five additives

significantly reduced NH_3 concentrations and three significantly reduced H_2S concentrations. Successful application of acid treatments and sphagnum peat moss reduced losses of NH_3 by 74.6% (Al-Kanani 1992).

Adding to some of the uncertainty as to whether these additives are indeed effective is the fact that a number of past evaluations of manure pit additives were not conducted independently of the manufacturer. As indicated by the results presented above, recently more of the evaluations are being carried out by independent testing facilities, removing some of the doubt regarding the results that may have been present in the past. However, most of the testing has been carried out on bench scale set ups (1 to 100 L), which may not adequately characterize the effectiveness of additives in actual barn applications. Many inconsistencies between commercial and bench-scale conditions exist. Bench-scale evaluations do not always correctly represent commercial surface area to depth ratios, manure additions are infrequent compared to barn conditions and manure is commonly homogenized (mixed) which does not occur to this extent in the actual manure channels. These differences between bench-scale protocol and actual barn conditions may introduce some question regarding the performance of the additives on a commercial scale when using bench-scale results as indicators. A factor of many of the experiments that may also contribute to some of the mixed reviews of additives is the limited number of replications that have been conducted. Limited replication combined with large variations in manure composition can produce results with minimal significance.

As a consequence of these identified limitations, it was suggested that this manure additive testing protocol be performed in commercial-scale manure channels and simulated outdoor storage. By carrying out the experiment in this manner, the results may be more indicative of what might be expected by hog producers when the additives are applied in their production facilities.

In light of what has been done in the past and what the needs of the parties involved are, our experiment was designed to assess the effectiveness of three manure pit additives under commercial conditions in both indoor and outdoor storage, with a large number of replicates. This study provides some useful information for pork producers and regulators/policy makers to make educated decisions regarding the potential benefit of manure pit additive use in intensive hog production facilities. In doing so, the barriers to expansion discussed above regarding odour nuisance and gas control, nutrient management and manure handling may be reduced and, all parties involved, including producers, neighbours and regulators, would profit.

Objectives

The objective of this research was to evaluate the effectiveness of three manure pit additives to reduce odour threshold and gas concentrations above the manure surface, to reduce solids and waste strength, to maintain nutrient and micronutrient content and availability in the manure in commercial-scale manure pits and simulated lagoons.

To do so, different analyses were made in two phases of the experiment, indoor with manure channels and outdoor phase with simulated lagoon representing the stages of manure storage while it is at the production facility.

Observations

Experimental Limitations

In this experiment, a number of possible variation sources were identified. Those sources of variation were either human or procedural for the preparation of the additives, the sampling techniques and the analysis.

The indoor experimental set up was designed to determine the effectiveness of the additives over a range of manure compositions and production rates that might exist in commercial facilities. Variation in manure production amongst pigs was controlled by regrouping the pigs into four pens. This arrangement led to large variations in manure composition and production rate between manure pit positions within a same pen. Differences in manure production rates and of some manure parameters are displayed in Table 1. In retrospect, it may have been better to conduct the experiment in 16 pens, each with nine pigs, located over the 16 manure channels. This would likely have standardized manure composition and production rate relative to manure pit position, making comparisons between additive means easier and more powerful. However, this arrangement would have negated the effort to test the additives over a wide range of manure compositions and production rates.

Manure sampling always presents limitations as the product studied is very heterogeneous. Some variations can come from sampling in the barn as well as sub sampling realised by the laboratory making the analysis.

The transfer protocol was likely the other largest source of variation in the experiment. The problem encountered with the transfer protocol was that relatively large volumes of manure needed to be transferred over fairly long distances and that the manure in the channels was not very homogenous. As a result, it appears that the ratio of solids to liquids in the manure was altered during the transfer process. It is logical that the liquids would have been more easily pumped as no thorough homogenisation of the channel was done to limit possible volatilisation of NH_3 and H_2S. The problem was identified by slurry components that should have been conserved through time (i.e. no emission via volatilization) and were observed to have large reductions between Days 35 and 63. Table 2 summarises the losses of insoluble components that occurred between these two sampling times.

Table 1: Mean environmental conditions and manure characteristics in the indoor (five weeks) and outdoor (four weeks) experiments.

	Indoor Experiment		Outdoor Experiment
	Trial 1 (n=16)	Trial 2 (n=16)	(n=16)
Ambient Environment			
Ambient Temperature (°C)	23.9	17.8	25.5
Min Ambient Temperature (°C)	19.7	16.5	11.2
Max Ambient Temperature (°C)	31.2	23.5	44.1
Manure Pit Positions			
Position 1			
Manure Temperature (°C)	22.5	16.3	N/A
Manure Production Rate ($L \cdot pig^{-1} \cdot day^{-1}$)	10.8	9.6	N/A
Dilution Factor (%)	9.0	9.6	N/A
pH	7.19	7.36	7.73
Electric Conductivity (mS/cm)	29.9	33.7	49.0
Position 2			
Manure Temperature (°C)	22.4	16.3	N/A
Manure Production Rate ($L \cdot pig^{-1} \cdot day^{-1}$)	10.2	5.7	N/A
Dilution Factor (%)	9.5	14.7	N/A
pH	7.14	7.32	7.74
Electric Conductivity (mS/cm)	28.2	29.4	30.5
Position 3			
Manure Temperature (°C)	22.4	16.4	N/A
Manure Production Rate ($L \cdot pig^{-1} \cdot day^{-1}$)	7.1	2.0	N/A
Dilution Factor (%)	15.3	23.5	N/A
pH	7.05	7.20	7.67
Electric Conductivity (mS/cm)	19.8	20.6	14.3
Position 4			
Manure Temperature (°C)	22.4	16.5	N/A
Manure Production Rate ($L \cdot pig^{-1} \cdot day^{-1}$)	4.5	1.3	N/A
Dilution Factor (%)	18.5	37.0	N/A
pH	6.89	7.14	7.63
Electric Conductivity (mS/cm)	18.5	18.6	16.6

Table 2: Percent losses of insoluble components from Day 35 to Day 63, by additive and manure pit position (n=4).

Component	Percent Loss by Additive (%)			
	Control	ABC*	PB†	WB‡
Copper (Cu)	-62	-69	-45	-42
Magnesium (Mg)	-70	-80	-60	-48
Phosphorus (P)	-56	-59	-55	-44
Total Solids (TS)	-33	-44	-28	-24
Zinc (Zn)	-73	-81	-57	-56
	Percent Loss by Manure Pit Position (%)			
	1	2	3	4
Cu	-31	-34	-78	-88
Mg	-48	-46	-80	-92
P	-33	-41	-68	-80
TS	-17	-26	-41	-45
Zn	-47	-49	-87	-96

*ABC: American BioCatalysts
†PB: Pit Boss
‡WB: Westbridge

Large amounts of insoluble components have not been transferred for the storage phase, in quantities that are not likely attributable to treatment effects. The pattern of losses were reasonably consistent relative to manure pit position and additive, unfortunately, no sample was taken on Day 36 to verify the efficiency of the transfer procedure. As a result, the differences between results on Days 35 and 63 were due to both additive effect and the inconsistent transfer procedure. These effects cannot be separated from one another making assessment of treatment effects for Day 49 and 63 results imprecise in most cases. Results from insoluble components were not interpretable because the exact portion of solids lost in each transfer is not known. Insoluble components were affected by the loss of solids because many of these components have a portion of their overall pool in the solid form. As we cannot calculate exactly what portion was lost, we cannot determine what the activity of the additive would have been if none were lost. Therefore, results from Days 49 and 63 for soluble and insoluble components cannot be interpreted confidently. However, some Day 49 and 63 results could be interpreted. Results that could still be interpreted were odour threshold and H_2S concentrations. Portions of the manure that can contribute to the production of these emissions have been lost, but correlations were made between odour threshold and H_2S concentrations and total solids concentration.

Correlations indicate very weak relationships between solids concentrations and odour thresholds (R^2 = 0.01 to 0.18) and H_2S concentrations (R^2 = 0.00 to 0.07) for the additives. Correlations for CO_2 and NH_3 were conducted, but the correlations were too high ($R^2 < 0.50$) to consider the effect of solids losses on these other parameters to be negligible. Odour thresholds and H_2S concentrations from Days 49 and 63 will be presented, but should be considered with caution due to the transfer procedure problem.

This section was not intended to detract from the quality of the work or the importance of the findings in this experiment. The purpose was to provide the reader with the necessary background information on the experiment to be able to interpret the findings from a proper viewpoint.

Deviations from Protocol

During the experiment two deviations from protocol occurred, leading to missing data. During the first indoor trial (July 11, 1998), pigs housed in pen 4 tore from the wall the water line for bowl waterers over channels 13 (ABC) and 14 (PB), causing these channels to become nearly flooded. This caused a deviation in the experiment resulting in channels 13 and 14 being abandoned for this room turn. Fortunately the leaking waterline was found and repaired before channel 15 was affected. Other deviations were due to the laboratory's inability to carry out total dissolved solids (TDS) and total suspended solids (TSS) analyses on samples from Days 28 and 35 in the second indoor trial. As a result of the missing data, the LSMEANS (least square average) procedure was used during statistical analysis.

Interpretation of Results

In almost all of the manure components that were evaluated, the differences between additive and control means were determined to be not statistically significant ($P<0.05$). Insignificant results do not necessarily indicate that additives were unable to produce improvements relative to control, but were a function of the variability encountered in the measurements. Throughout the experiment, a high degree of variability was observed, and the number of replicates that were carried out was found to be inadequate. The combination of a high degree of variability and low number of repetitions translated into large LSDs used for mean separation during statistical analysis. These LSDs (least square difference) often represented a large portion of the control mean (<30%), which imply that relatively large improvements had to be produced by the additives to be considered statistically significant. In most cases, smaller improvements might still be practically beneficial. Thus, percent difference between the additive and control means became a valuable tool in describing additive effectiveness.

Considering the variability observed, the results obtained from this experiment only represent the effectiveness of the three additives under the experiment conditions which were representative of commercial grower-finisher barns and could be different under different manure parameters (feed, channel, depth, temperature).

Environmental Conditions

Throughout the experiment, measurements were made of ambient temperature (mean, minimum and maximum), mean manure temperature, mean manure production and dilution (due to initial water addition) rates, pH and electrical conductivity. Table 1 summarises these conditions.

Ambient temperature data indicated that summer and fall temperatures were quite different, with the summer trial temperature being approximately 6°C warmer than the fall temperature. Both indoor trial temperatures were slightly lower than the temperature in the outdoor trial. These temperature differences directly impacted manure temperature.

Similar to the ambient temperatures, mean manure temperatures in the first trial were approximately 6°C warmer than in the second trial, which may have impacted the microbiology and chemistry of the manure. Higher manure temperatures can result in stimulated microbial activity, increased solubility and more rapid reaction kinetics in the manure, ultimately providing higher decomposition rates. In comparison with past studies, manure temperatures corresponded with previously reported ranges of 15 to 22°C (Zhu et al. 1997; Patni and Jui 1993). Heat-related pig behaviour modification that could influence manure composition and production rate might have included reduced feed intake, increased water intake and wastage, and reduced activity.

The study of manure production rates relative to manure pit position indicated the presence of a dunging gradient (Table 1). As manure pit position increased, manure production rate decreased. This observed dunging gradient was the opposite of the expected gradient. This suggested that manure production was affected by alterations in sleeping and eating patterns due to ambient air conditions. Observations suggested that the pigs tended to rest and sleep along the walls. Due to this sleeping pattern, the pigs dunged more in the middle of the room over manure pit positions 1 and 2.

Differences in manure production rate could potentially affect gas and odour production, solids composition, nutrient and micronutrient levels and manure strength. Higher production rates should correlate with increased concentrations of these manure components. In comparison with the reported MWPS (1993) manure production rate of 5.45 to 7.26 $L \cdot pig^{-1} \cdot day^{-1}$, the mean experimental manure production rate of 6 $L \cdot pig^{-1} \cdot day^{-1}$ is considered to be representative of average commercial conditions.

Manure dilution rates varied between trials and manure pit positions. Manure production in the second indoor trial, in terms of overall volume, was lower than the first indoor trial. As a result of this difference in overall volume, the 350-L of water added before each trial represented a larger dilution at the end of the second trial than the first trial. Dilution rates would also affect gas and odour production, solids composition, nutrient and micronutrient concentrations and manure strength. The combined effects of manure production and dilution rate could greatly impact chemistry and microbiology of the manure, resulting in a high degree of variability in manure composition relative to manure pit position.

Electrical conductivity and pH were measured to characterize manure chemical conditions. Electrical conductivity was used as an indicator of the amount of ions present in the manure. In the experiment, the electric conductivity of each manure pit position remained either nearly constant or increased with time. This was indicative of a solubilization of manure components into ionic forms. Differences in electric conductivity relative to manure pit position were present, with the electric conductivity in manure pit position 1 being the highest and steadily decreasing to manure pit position 4. The pH measurements indicated that the manure was neutral to mildly basic and no difference between manure pit positions was observed.

Odour and Gas Evaluation

Odour Threshold

Odour threshold measurements from trial 1 (summer indoor and outdoor trials) and the combined indoor trials (1 and 2) are presented in Tables 3 and 4, respectively. Differences between additive means in Trial 1 were only significantly different ($P<0.05$) on Day 63, based on log transformations of odour thresholds. The control mean odour threshold was highest on Day 28 (1,030 OU (odour units)), stabilising until Day 49 at (1,010 OU) and finally decreasing to 680 OU on Day 63. This indicated that most of the odour emission during this relatively hot period of the year occurred in the manure channels with some dissipation in the lagoons. Part of the dissipation may have resulted from the transfer problem encountered between the indoor and outdoor trial.

The ABC additive was the most consistently effective additive during the indoor portion of the experiment, reducing the odour threshold relative to control in the range of 11 to 16%. The levels of 870 and 900 OU measured on Days 28 and 35, respectively, were the lowest of any of the additives on any of these days. In the outdoor portion of the trial, ABC was not found to be very effective on Day 49 resulting in an odour threshold higher than the control, but on Day 63, ABC performed better, providing a 31% reduction; that reduction was the smallest of any of the additives. The PB additive did not produce any odour reductions in the indoor portion of the experiment, but produced the greatest reductions in the outdoor phase. These reductions were 16 and 66% lower than the control thresholds on Days 49 and 63. The 66% percent reduction was the only reduction that was statistically ($P<0.05$) lower than the control in the entire experiment. The WB additive also produced good odour threshold reductions in the outdoor experiment (9 and 37%), but did not produce any substantial reductions in the indoor trial.

In terms of the first indoor trial, ABC produced the best overall odour threshold reduction. This suggests that the microbial and enzymatic activity of ABC is the best option for odour threshold reduction in the indoor manure channels. In terms of the outdoor portion of the first trial, both PB and WB additives produced good odour reductions. In the simulated lagoons, the chemical activity of the PB additive appeared to be slightly better in suppressing odour production than the habitat enhancement WB produced.

Some of the odour threshold reductions produced by the additives tended to be slightly lower than other reported reductions (AURI 1997; Zhu et al. 1997) but were generally within the same limits suggesting that different protocols could be able to produce comparable results.

Table 3 Means and percent differences from control means, for odour threshold and H_2S for Trial 1.

Component	Sampling Day	Treatment							
		Control		ABC		PB		WB	
		Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	Mean	% Diff.
Odour Threshold (OU)*	Day 28	1030 a	0	870 a	-16	1030 a	0	1010 a	-2
	Day 35	1010 a	0	900 a	-11	1250 a	24	1220 a	21
	Day 49	1010 a	0	1070 a	6	850 a	-16	920 a	-9
	Day 63	680 a	0	470 a	-31	230 b	-66	430 a	-37
H_2S (ppm)	Day 28	0.63a	0	0.97 a	54	2.62 a	316	0.91 a	44
	Day 35	2.00 a	0	0.85 a	-58	0.48 a	-76	0.60 a	-70
	Day 49	9.38 a	0	4.03 a	-57	8.09 a	-14	3.13 a	-67
	Day 63	0.56 a	0	0.41 a	-27	0.37 a	-34	0.18 a	-68

Separation of means by row using LSD, $P>0.05$, $df = 15$

* Statistics carried out on log transformations of odour threshold values

Table 4 Air measurement means and percent differences for the combined indoor trials.

Component	Sampling Day	Treatment								LSD
		Control		ABC		PB		WB		
		Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	
Odour Threshold (OU)	Day 28	770 a	0	810 a	5	940 a	22	730 a	-5	*
	Day 35	1030 a	0	990 a	-4	1080 a	5	920 a	-11	*
H_2S (ppm)	Day 28	0.44 a	0	0.70 a	57	1.35 a	205	0.56 a	25	0.9
	Day 35	1.19 a	0	0.51 a	-57	0.29 a	-76	0.38 a	-68	1.1
NH_3 (ppm)	Day 28	12.4 a	0	11.7 a	-6	11.8 a	-5	10.1 a	-18	8.6
	Day 35	14.9 a	0	9.9 a	-33	16.3 a	9	12.1 a	-19	6.8
CO_2 (ppm)	Day 28	770 a	0	1190 a	55	1220 a	58	1010 a	31	621
	Day 35	920 a	0	620 a	-33	1060 a	15	910 a	-1	457

Separation of means by row using LSD, P>0.05, df = 31

* Separation of means using log values of observations

When data from both indoor trials were combined (Table 4), differences between additive odour threshold means were not statistically significant ($P<0.05$) and the variation among means was very large. The control odour threshold was 770 OU on Day 28 and rose to 1,030 OU on Day 35. On Day 28, WB was the only additive able to produce a minor (5%) odour threshold reduction, although this reduction is of little practical significance. Both ABC (810 OU) and PB (940 OU) did not provide any reduction in odour threshold at that time. These results indicated that application of these additives does not provide any real benefit at Day 28. The same can be claimed of the additives' ability to reduce odour emissions on Day 35. On Day 35, ABC and WB were able to produce small (4 and 11%) odour threshold reductions of little practical value. Pit Boss (1,080 OU) was the least effective on Day 35, resulting in an odour threshold that was 5% higher than the control. This was inconsistent with the findings of AURI (1997) where PB resulted in a 48% odour threshold reduction. The differences may be attributable to differences in barn management or environmental conditions.

Overall, it is unlikely that small improvements observed with ABC and WB additives represented either a beneficial or a detrimental effect, whereas, the 22% increase in odour threshold produced by the PB additive likely represented a noticeable difference. In general there is too much variation in odour threshold results to provide a statistical analysis.

When comparing odour thresholds with gas and solids concentrations from this experiment, strong correlations were not found.

Hydrogen Sulphide Reduction

Data from trial 1 (Table 3) suggest that none of the additives were able to significantly ($P<0.05$) reduce H_2S concentrations relative to control. On Day 35, the reductions ranged from 57 to 76% indicating that the additives may be suppressing the sulphur metabolism that contributes to H_2S evolution. On Day 49, the H_2S concentrations for all of the additives and the control increased several fold over the corresponding Day 35 concentrations. Many factors may have contributed to these increased concentrations, including increased temperature in the outdoor storage lagoon and partial homogenization during the transfer protocol. Once, again, caution should be used when interpreting Day 49 and 63 (outdoor) results. On Days 49 and 63, all of the additives produced reductions in H_2S concentrations in the range of 14 to 76%. From Day 35 on, ABC and PB appeared to lose some of their ability to suppress H_2S emissions while WB maintained a consistent level of reduction.

The levels of H_2S in this study are low compared to the colorimetric tube detection limit (0.2 ppm). The low control concentrations of H_2S on Days 28, 35 and 63 also indicate that reductions produced by the additives may not have been necessary to reduce health and emission concerns, but the continued suppression on Day 49 indicates that the additives may be effective at higher levels of H_2S.

Means from the combined indoor trials concurred with trial 1 findings. The variation in concentrations, as indicated by relatively large LSD values, is quite large. These large variations in H_2S concentrations were consistent with large variations observed in odour

threshold and NH_3 concentration. On Day 28, none of the additives were able to reduce the mean H_2S concentration relative to control. Then on Day 35, all of the additives reduced H_2S in the range of 57 to 76%, representing substantial reductions. However, none of the reductions were statistically significant ($P<0.05$).

Ammonia Reduction

Reductions of ammonia concentration relative to the control concentration represent a benefit in terms of improving air quality in the barn, maintaining nitrogen in the manure and possibly, the longevity of the facility. Mean ammonia concentrations indicated no significant differences ($P<0.05$) between additives and control (Table 4). The absence of significant differences may have resulted from the lack of power in the experiment illustrated by LSDs of 69% of the control concentration on Day 28 and 46% of the control concentration on Day 35. Control concentrations of ammonia were 12.4 and 14.9 ppm on Days 28 and 35. This reveals a natural increase in ammonia emission resulting from native microbial and enzymatic activity in the manure and once again indicated that a 28-day retention time in the manure channels may be beneficial. This increase in NH_3 gas production was consistent with the trend observed in odour and H_2S control means. Control ammonia concentrations in this experiment were at the lower end of the previously reported ranges of 9 to 56 ppm (Heber et al. 1997; Patni and Jui 1993; Riskowski et al. 1991).

The ABC additive produced a slight reduction (6%) in ammonia concentration on Day 28 and a 33% reduction on Day 35. The PB additive also produced a slight decrease (5%) in ammonia concentration on Day 28, but failed to result in any reduction compared to control in the remainder of the experiment. Westbridge was the only additive that provided a consistent reduction in ammonia for the whole experiment. The ammonia reductions produced by WB were approximately 18% lower than the control.

In terms of overall effectiveness, all of the additives produced minor reductions in ammonia which were not statistically significant. This is in contrast to other experiments, which have generally indicated that similar products have produced NH_3 reductions in the range of 40 to 70% (AURI 1997; Heber et al. 1997; Martinez et al. 1997). Ultimately, the reductions produced by the additives were minimal and the control concentrations were not in a range that should be considered a large emission.

Carbon Dioxide

The majority of CO_2 in the barn is produced through pig respiration but a small fraction is produced during degradation of the manure. The manure-derived CO_2 fraction was collected and quantified, allowing an additive effect to be determined. Similar to the gases that were previously discussed, differences in CO_2 concentrations do not exhibit a significant additive effect ($P<0.05$) but a significant trial effect was observed ($P<0.05$) with the CO_2 concentrations in the first trial being larger than the second trial. Control concentrations were 770 and 920 ppm on Days 28 and 35, respectively. The increase in gas concentration through time that was previously noted for the other gases was also present in the CO_2 results, appearing to be a natural tendency in the control manure.

On Day 28, all additives resulted in CO_2 concentrations 30 to 60% higher than the control. This suggests that the additives were promoting higher rates of degradation in the manure. By Day 35, only PB maintained a higher level of CO_2 (15%), while WB was near the control level and ABC had decreased to 33% below the control level. The differences in CO_2 concentration on Day 35 suggests that PB was more effective in stimulating respiration, while the other additives began to exhibit reduced degradation rates at or below the control rate. None of the additives produced CO_2 levels that would be harmful to workers or pigs.

Considering the overall effect of the additives on air characteristics, a few general points can be made. First, a 28-day manure retention time in the manure channels would be beneficial if no treatment were available but in cases where 35 days or more were required for the operation, the additives may produce benefits. Second, the apparent ability of the additives to reduce H_2S and NH_3 concentrations does not necessarily result in corresponding odour concentration reductions. The ABC treated manure had similar or higher H_2S and NH_3 concentrations than the other treated manures, but resulted in the greatest odour concentration reduction of any of the additives.

Solids Evaluation

Total Solids Breakdown

A reduction in TS can have some effect on manure handling ease. No significant differences ($P<0.05$) between additive means were found (Table 5). Control levels on Days 28 and 35 indicated a trend of decreasing TS through time, from 43,200 to 37,300 mg/L. This suggested a natural breakdown of solids in the manure resulting from the native microbial population. In most cases the naturally occurring bacteria in the manure produced TS levels that were lower than the additive levels indicating that the additives may be of little value in TS reduction. The control levels of TS were within previously reported ranges measured by Zhu et al. (1997) and Riskowski et al. (1991).

During the indoor trial, the ABC additive did not reduce TS levels relative to control. Total Solids levels were 24 and 4% higher than the control on Days 28 and 35. Apparently, the added microbes and enzymes in the ABC additive did not promote solids breakdown in the indoor experiment, although the Day 35 level was the lowest level reached by of any of the additives.

Table 5 Solids measurement means and percent differences for the combined indoor trials.

Component	Sampling Day	Treatment								LSD
		Control		ABC		PB		WB		
(mg/L)		Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	
TS	Day 28	43200 a	0	53600 a	24	39600 a	-8	49400 a	14	20600
	Day 35	37300 a	0	38600 a	4	42700 a	15	45300 a	21	16000
TSS	Day 28	28500 a	0	38400 a	35	15300 a	-46	41100 a	44	23900
	Day 35	33400 a	0	35000 a	5	34800 a	4	27000 a	-19	19400
TDS	Day 28	9700 a	0	11800 a	22	8800 a	-9	9400 a	-3	3820
	Day 35	9000 a	0	13200 a	47	10300 a	14	12500 a	39	3780
TVS	Day 28	33900 a	0	41800 a	23	30500 a	-10	38600 a	14	16600
	Day 35	27800 a	0	27200 a	-2	33100 a	19	34200 a	23	13800

Separation of means by row using LSD, $P>0.05$, $df = 31$

The PB additive resulted in TS levels with little change through time. On day 28, PB resulted in the only TS reduction (8%) produced by an additive, but it was not statistically significant. If PB were used as an additive in barns, the best management strategy to adopt might be a 28-day retention time in the manure channels to keep TS levels low. By keeping the TS levels low, manure handling might be improved. The better performance on Day 28 may have also resulted from the nature of addition of the additive. With only a single addition on the initial day of the treatment phase, perhaps the effectiveness of the additive was reduced with time. More frequent additions may have produced better results. If the retention time was in the 35-day range, this benefit might be negated because PB resulted in the second highest level of TS (42,700 mg/L) on Day 35, possibly making manure handling relatively more difficult compared to the ABC additive.

The WB additive resulted in TS levels slightly higher than control in the indoor trial, with the highest TS level on Day 35. In terms of manure handling ease (TS reduction), no real benefit above what can be expected in untreated manure channels is likely to be gained through the application of any of the additives. These results are inconsistent with other studies (Zhu et al. 1997) that have indicated that similar products have promoted TS reductions up to approximately 25%. Again, differences in the procedure and the environment may contribute to these conflicting results.

Solids Solubilization

In addition to solids breakdown, manure-handling ease may also be improved by solubilizing solids. To evaluate the effectiveness of the additives at solubilizing the solid fraction of the manure, both TSS and TDS levels were determined. Effective solubilization is represented by a transformation of TSS to TDS in the manure. Neither TSS nor TDS results had significant differences ($P<0.05$) among means, but the power of the experiment was again limited (Table 5). Least Significant Differences for separating additive means represented 84 and 58% of the control mean for TSS and 39 and 42% of the control mean for TDS on Days 28 and 35, respectively. For TDS data on Day 28, the second trial produced significantly ($P<0.05$) larger TDS concentrations than the first. The increased solubility does not seem to stem from environmental conditions like temperature. If temperature had influenced TDS results, the first trial with the higher temperature should have resulted in more solubilization.

Regarding TSS, the trend displayed by the control was an increase on Day 35 (33,400 mg/L) from the level on Day 28 (28,500 mg/L). This was accompanied by a decrease in TDS on Day 35 (9,000 mg/L) from the level on Day 28 (9,700 mg/L). This combination of increasing suspended solids and decreasing dissolved solids indicated that solubilization was not a natural tendency in the untreated manure.

The ABC additive did not appear to successfully solubilize solids relative to the control. Results indicated elevated TSS levels combined with elevated TDS levels compared to the control on both sampling days. The elevated TDS levels were indicative of increased solubilization but the elevated TSS levels reduce the impact of the solubilization.

The PB additive resulted in lower levels of TSS (46%) and TDS (9%) relative to control on Day 28, but increased to 34,800 and 10,300 mg/L of TSS and TDS respectively on

Day 35. This suggests that the additive was more effective on Day 28 than Day 35. If PB additive were used in the barn, adopting a 28-day retention time may provide more benefit in terms of solids solubilization than a 35-day retention time.

The WB additive reduced TSS, in combination with increased TDS levels from day 28 to 35. On Day 28, WB did not perform better than the control but appeared better than the control on day 35. On Day 35, TSS was reduced by 19% and TDS was increased by 39%.

Total Volatile Solids Evaluation

The total volatile solids (TVS) fraction is the fraction of solids that can contribute to odour and gas production. The additive effect was not found to be significant ($P<0.05$) in terms of differences between additive means (Table 5). Control manure was observed to decrease in TVS throughout the experiment indicating that the volatile fraction of solids was either being solubilized or converted into gas and released to the atmosphere. As solubilization was quite low in the control, it was likely released to the atmosphere.

This tendency was also observed in the ABC and WB treated manures, with the apparent decrease associated with ABC being larger. The ABC levels dropped from 41,800 to 27,200 mg/L while WB decreased from 38,600 to 34,200 mg/L. In light of these additives' performances relating to solids solubilization and gas production, it is possible that volatile solids were being solubilized rather than converted into gaseous emissions by WB, but not ABC. Still, this interpretation of these results must be made with caution because determining whether reduced TVS levels in ABC and WB treated manure represented a decrease in odour and gas production potential or a release in the form of gas is difficult. The PB additive maintained a fairly stable level of TVS throughout the experiment.

Considering the overall effect of the additives on solids, it was apparent that none of the additives produced solids reduction and only WB provided some apparent solubilization. As solids reduction is likely one of the main reasons for using the additives, the tested additives may not provide much benefit.

Nutrient Evaluation

Nutrient analyses included nitrogen (total Kjeldahl nitrogen (TKN) and NH_4-N), phosphorus (P and ortho-phosphate (OPO_4) and potassium (K) determinations. This section describes and discusses the findings of the experiment relating to nutrient levels in the manure (Table 6).

Nitrogen Retention and Availability

The two nitrogen fractions that were analyzed were TKN and NH_4-N, representing total oxidizable forms of nitrogen and the plant available form, respectively. Total Kjeldahl Nitrogen measurements indicate no statistically significant differences ($P<0.05$) between additive means (Table 6). Control TKN levels in the manure decreased with time, from 5,270 (Day 28) to 4,970 mg/L (Day 35). This indicated that a 28-day retention time may provide the best nitrogen retention if the manure was untreated, because the nitrogen metabolism likely increased with time.

Table 6 Nutrient, micronutrient and COD measurement means and percent differences for the combined indoor trials.

Component	Sampling Day	Treatment								LSD
		Control		ABC		PB		WB		
(mg/L)		Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	
TKN	Day 28	5270 a	0	6290 a	19	5290 a	0	5070 a	-4	1760
	Day 35	4970 a	0	5770 a	16	5590 a	13	5300 a	7	1480
NH_4-N	Day 28	3350 a	0	3530 a	5	3200 a	-5	3350 a	0	809
	Day 35	3060 a	0	3820 a	25	3550 a	16	3330 a	9	858
P	Day 28	2010 a	0	2130 a	6	2480 a	23	2210 a	10	1335
	Day 35	1190 a	0	1330 a	12	1280 a	8	1240 a	4	597
OPO_4	Day 28	660 a	0	820 a	24	640 a	-3	810 a	23	374
	Day 35	453 a	0	531 a	17	527 a	16	560 a	24	286
K	Day 28	2220 a	0	2970 a	34	2470 a	11	2690 a	21	734
	Day 35	2420 a	0	3240 b	34	2630 ab	9	2820 ab	17	746
Cu	Day 28	12.4 a	0	14.6 a	18	13.8 a	12	16.2 a	31	7.8
	Day 35	11.5 a	0	12.1 a	5	13.4 a	17	13.4 a	17	5.7
Mg	Day 28	530 a	0	630 a	19	520 a	-2	660 a	25	326
	Day 35	532 a	0	551 a	4	546 a	3	551 a	4	285
Na	Day 28	530 a	0	678 a	28	587 a	11	623 a	18	158
	Day 35	525 a	0	692 a	32	574 a	9	619 a	18	159
Zn	Day 28	37.92 a	0	43.37 a	14	34.43 a	-9	45.30 a	20	25.5
	Day 35	35.93 a	0	36.60 a	2	37.00 a	3	38.19 a	6	19
COD	Day 28	38800 a	0	40400 a	4	36900 a	-5	44200 a	14	15495
	Day 35	33000 a	0	40000 a	21	41100 a	25	40500 a	23	15958

Separation of means by row using LSD, P>0.05, df = 31

Increased nitrogen metabolism could result in losses of nitrogen in volatile forms. Control TKN values were 2 to 3 times higher than TKN measurements reported in previous experiments (Lorimer 1996; Barrington 1993).

A decline in TKN was also observed in the ABC additive from Day 28 to 35. This decline did not adversely affect the nitrogen retention associated with the additive. In spite of the losses, ABC had the highest levels of TKN on both days, with levels about 16 to 19% greater than the control. This suggests that ABC may be active in retaining nitrogen for the duration of the experiment.

Neither the WB nor PB additive displayed TKN levels higher than the control on Day 28 but both increased in TKN from Day 28 to 35. These TKN levels were maintained at 7% (WB) and 13% (PB) higher than the control on Day 35.

Ammonium-nitrogen levels representing the plant available fraction are perhaps more important in terms of immediate fertilizer value than the TKN measurements. Ammonium-nitrogen measurements indicated no significant differences ($P<0.05$) between additive means, but a significant difference ($P<0.05$) was found between trials (Table 6). Ammonium levels in the second trial were significantly higher than in the first trial. This may be a result of reduced ammonia production in the second trial when the temperatures were lower.

Control data indicated that the natural tendency was to maintain a relatively constant level of NH_4-N for the duration of the experiment. On days 28 and 35, the levels were 3,350 and 3,060 mg/L. This range of NH_4-N was higher than most previously reported values that ranged from 747 mg/L to 2,467 mg/L (Lorimer 1996; Barrington 1993), but below the value of 5,727 mg/L reported by Heber et al. (1997).

During the trial, ABC additive resulted in increases in NH_4-N, between days 28 and 35. On both sampling days, the levels were above the control levels by 5 to 25%. These apparent increases in available nitrogen may reflect the microbial and enzymatic activity of the additive and could be valuable in terms of fertilizer value. The PB NH_4-Nlevels also increased from Day 28 to 35 but did not result in as much being present as the ABC treatment. The NH_4-N level of 3,550 mg/L on Day 35 suggests a benefit of 16% more available nitrogen resulting from the chemical activity of the additive. Westbridge resulted in a consistent level of NH_4-N, providing a 9% increase relative to control on Day 35. Overall, the additives may provide some benefit in terms of nitrogen availability, especially at the retention time of 35 days.

Phosphorus Retention and Availability

Phosphorus retention and availability are a consideration when manure is land-applied as a fertilizer. The differences between phosphorus levels found in the additives (Table 6) were not statistically significant ($P<0.05$). A natural decrease in control levels was evident in the results, beginning at 2,010 mg/L on Day 28 and falling to 1,190 mg/L on Day 35. This could be due to a decrease in the rate of phosphorus addition to the manure and/or increased dilution with time. The control measurements corresponded with previously reported values ranging from approximately 1,400 to 1,500 mg/L (Heber et al. 1997; Barrington 1993).

All of the additives displayed the tendency to reduce phosphorus throughout the experiment but maintained levels higher than the control. For the indoor trial, all of the additives showed similar concentrations suggesting that their modes of action promoted similar phosphorus retention. Overall, the additives appeared to be successful, as all were able to retain phosphorus at levels above the control in the range of 4 to 23%.

Ortho-phosphate levels, representing the plant available fraction, are perhaps more important than total phosphorus measurements in terms of immediate fertilizer value. Similar to the phosphorus results, OPO_4 results indicated that the differences between additive means (Table 6) were not statistically significant ($P<0.05$). Control levels of OPO_4 on Days 28 and 35 were 660 and 453 mg/L, respectively. These values indicated that the control maintained approximately the same proportion of the total phosphorus in the plant available form on both sampling days.

The tendency for OPO_4 levels to decrease with time was present in the results representing the additives' performance. During the indoor trial, both WB and ABC were able to maintain OPO_4 levels at approximately 20% greater than the control. Unlike the other additives, PB was unable to promote phosphorus availability relative to control on Day 28, resulting in a 3% decrease. However, on Day 35, the PB OPO_4 level had rebounded to a level about 16% higher than the control. Therefore, a 35-day retention period might be the best management strategy in terms of phosphorus retention when applying PB.

These findings suggest that all of the additives might be able to provide OPO_4 retention compared to the control, which is a positive effect in terms of nutrient value of the manure.

Potassium Retention

Potassium is another essential nutrient important in the fertilizer value of the manure. Analyses were carried out to determine the ability of the additives to maintain K levels higher than those observed under control circumstances. On Day 28, differences between additive means were not significantly different ($P<0.05$) and on Day 35, ABC was significantly higher than the control (Table 6). On Day 28, the control level was 2,220 mg/L and then it increased to 2,420 mg/L on Day 35. This indicates that K addition exceeded the dilution of the manure between the two sampling days.

The ABC (2,970 mg/L), PB (2,470 mg/L) and WB (2,690 mg/L) levels were all higher than the control on Day 28. Day 35 results suggest that all of the additives produce benefits in terms of K retention but only ABC retention was significantly greater than the control. Thus, the microbial and enzymatic action of the ABC additive was much more effective than the control and slightly better than the other additives. Overall, K retention appeared to be an area where all of the additives were able to provide some benefit.

In terms of overall nutrient retention and availability, all of the additives appear to be able to produce benefits. The added value of increased overall and plant available nutrient concentrations from the application of the additives is one of the strongest advantages to using them. This value is passed on to the producer in terms of increased value in the manure and potential increases in crop yields.

Micronutrient Evaluation

Micronutrients in the manure are also a valuable resource when manure is applied as a fertilizer, but can also exhibit toxic effects at high levels. The objective of micronutrient analysis was to determine if any of the additives would provide micronutrient levels above control levels. The micronutrients considered in this experiment were Cu, Mg, sodium (Na) and Zn. None of the differences between additive means representing Cu, Mg or Zn concentrations (Table 6) were statistically significant ($P<0.05$).

The control maintained a fairly constant level of all micronutrients between Days 28 and 35. Copper and Zn levels were observed to have had a minor drop in concentration between the sampling days, while the Mg and Na levels remained almost identical. None of these levels appear to be in a harmful range for use as a fertilizer and adopting a 28 or 35 day retention period over the other option could derive little or no advantage.

The ABC additive maintained higher levels of all of the micronutrients than the control on both sampling days. The Cu level of 14.6 mg/L on Day 28 was the second highest of the additives and the 12.1 mg/L determined for Day 35 was the lowest. This indicates that a 28-day retention period may provide more Cu during landspreading. The Mg levels of ABC on Days 28 and 35 were higher than the control by 19 and 4% indicative of a potential benefit in terms of Mg in the fertilizer. Again, a 28-day retention period would have provided more benefit. Zinc levels in the ABC manure were highest on Day 28 (43.37 mg/L) falling to 36.60 mg/L on Day 35. This suggests that the 28-day retention time may be beneficial in terms of Zn as well. The only micronutrient concentration that increased with time was Na, with levels of 678 mg/L on Day 28 and 692 mg/L on Day 35. Overall, the action of the ABC additive appeared to be effective in maintaining micronutrient levels higher than the control level.

The PB additive was also reasonably effective in maintaining micronutrient levels higher than control but a 35-day retention time appears to be a better management strategy. On Day 28, PB resulted in Cu levels 12% greater than the control, which increased in the next seven days to 17% greater than the control. This may be a bit misleading because the actual concentration of the Cu was higher on Day 28. However, it is strange that the Cu level in PB was lower than the other treatments, considering that the additive itself consists of Cu. The amount of additive applied to the manure was very low which may have limited some of its effectiveness.

Magnesium and Zn levels also showed increases relative to the control levels from Day 28 to 35. The concentration of Mg went from 2% lower than the control to 3% greater than the control and the Zn levels rose from 9% less than the 3% greater than the control. Sodium measurements were the only indication of a decrease in beneficial activity of the additive relative to control on Day 35. The Na level dropped only a small fraction, but the percentage relative to the control dropped by 2% from 11 to 9% greater than the control. Overall, the PB additive appeared to be capable of providing beneficial retention of micronutrients through its chemical activity.

The WB additive provided excellent micronutrient retention, at a level almost always greater than the other additives. The only exception to this being that the ABC Na levels was higher. The data also indicated that a 28-day retention period would be the best

management strategy when using this product, in terms of increasing micronutrient content. Copper levels were 16.2 and 13.4 mg/L on Days 28 and 35 representing 31 and 17% increases relative to control. The previously mentioned Cu level, the Mg level of 660 mg/L and the Zn level of 45.30 mg/L on Day 28 were the highest of any of the additives indicating that WB was the best additive in terms of maintaining these micronutrients at that point in time. The Na levels of approximately 620 mg/L on Days 28 and 35 were not the highest levels observed with the treatments but still represented a beneficial retention of approximately 17% relative to the control. Overall, WB additive was likely the best additive in terms of micronutrient retention, especially if a 28-day retention strategy was adopted.

Regarding micronutrients, the overall performance of the additives is quite good. The PB additive may be the least effective additive in retaining micronutrients while both ABC and WB are very comparable. In total, all of the additives appeared capable of producing some positive retention of these critical manure components. Coupled with the effective nutrient retention and availability discussed in the previous section, the additives may be a benefit in terms of fertilizer value.

Manure Strength Reduction

Chemical oxygen demand was determined from the manure to be used as an indicator of the strength of the manure. To be considered beneficial, an additive should produce reductions in COD levels. None of the differences between additive means (Table 6) in the experiment were statistically significant ($P<0.05$). Control levels began at 38,800 mg/L on Day 28 and dropped to 33,000 mg/L on Day 35, indicating a natural tendency to decrease with time.

The ABC additive was able to produce a decrease in COD from Day 28 to 35, but these levels were both higher than the control. The PB additive produced a minor reduction in COD on Day 28, but was unable to reduce COD on the subsequent sampling day. The decrease in COD of 5% on Day 28 was the only improvement relative to the control in terms of COD reduction. This might indicate that a 28-day retention period would be the best management option in terms of COD reduction when PB was being used. Especially when considering that the level of 41,100 mg/L determined for Day 35 was the highest of any of the additives. The COD levels for WB indicate that WB provided the worst COD reduction of any of the additives on Day 28 and the second best on Day 35. Neither of these levels (44,200 and 40,500 mg/L) was a reduction relative to control. These levels were above the control by 14 to 23%. Considering all of the additives' abilities to reduce COD none appeared to provide any substantial improvements. Even the 5% reduction produced by PB on Day 28 would likely be inconsequential considering the level was still 36,900 mg/L. Regarding additive performance, it might be that the additives are in fact increasing COD levels. These findings do not agree with previous results from evaluations of similar products that have reportedly produced reductions of up to 25% (Zhu et al. 1997).

Overall Additive Performance

The overall performance of the additives are summarized in Table 7:

Table 7: Overall performance of the three manure pit additives.

Parameter	Treatment		
	ABC	PB	WB
Odour and Gas			
Odour Reduction (%)	NRed to 31%	NRed to 66%	NRed to 37%
H_2S Reduction (%)	NRed to 58%	NRed to 76%	NRed to 70%
NH_3 Reduction (%)	6 to 33%	NRed to 5%	18 to 19%
CO_2 Production (%)	NRet to 33%	15 to 58%	NRet to 31%
Solids			
TS Reduction (%)	NRed	NRed to 8%	NRed
Solids Solubilization	Little/no	Little/no	Little/no
TVS Retention (%)	NRet to 23%	NRet to 19%	14 to 23%
Nutrients			
TKN Retention (%)	16 to 19%	NRet to 13%	NRet to 7%
NH_4-N Retention (%)	5 to 25%	NRet to 16%	NRet to 9%
P Retention (%)	6 to 12%	8 to 23%	4 to 10%
OPO_4 Retention (%)	17 to 24%	NRet to 16%	23 to 24%
K Retention (%)	34%	9 to 11%	17 to 21%
Micronutrients			
Cu Retention (%)	5 to 18%	12 to 17%	17 to 31%
Mg Retention (%)	4 to 19%	NRet to 3%	4 to 25%
Na Retention (%)	28 to 32%	9 to 11%	18%
Zn Retention (%)	2 to 14%	NRet to 3%	6 to 20%
COD Reduction (%)	NRed	NRed to 5%	NRed
Cost ($/pig sold)	0.07	0.19	0.02

NRed: No reduction.
NRet: No retention.

Protocol Evaluation

Being that this experiment represents the first attempt to test manure pit additives on a commercial scale with greater control of environmental conditions and other factors that may contribute to variation, it is important to discuss the protocol. In general, the protocol seemed to be effective in evaluating the performance of the additives. It allowed all of the desired characteristics to be evaluated and appears to represent continuous barn activities well. One of the characteristics of the protocol that was both a strength and a weakness was the variation in manure composition that was encountered. The variation allowed the performance to be determined in a range of manure composition that might be encountered by producers but also contributed to the limited statistical power of the experiment. Another potential strength of the protocol was the evaluation over the

lifespan of the manure at the facility (indoor and outdoor storage). Unfortunately, the inadequacy of the transfer from indoor to outdoor led to some relatively large problems. In future attempts to replicate this work, transferring smaller amounts of manure or using a more appropriate transfer setup would improve the study tremendously.

Other ways to improve the experiment might be to have more continuous monitoring of gas emissions, better timing of the analyses and adding or eliminating some analyses. By increasing the frequency of gas measurements, a better understanding of the emission pattern through time may be accomplished. Better timing of analyses would include the following schedule of analyses. In the indoor phase it is most appropriate to measure odour, gases and solids, while odour, gases, solids, nutrients, micronutrients and waste strength would be appropriate at the beginning and the end of the outdoor phase. The reason that some of the analyses should only be conducted during the outdoor study is that these parameters are related to land application that would follow this phase. The fate of these characteristics is related to what happens in the indoor phase but the specifics are of little consequence in terms of the overall picture. In future trials, some of the nutrient and micronutrient analyses could be omitted because the value that these analyses offer is limited and it is unclear exactly how the additives can affect these parameters. The addition of nitrate determination might be of interest in future trials as nitrate leaching during land application is of environmental relevance. On the whole, it appears that the protocol was quite successful in allowing the hypotheses that were set forward, to be tested.

Conclusions

Three manure pit additives have been tested in full-scale manure channels and simulated outdoor lagoons. The experimental design allowed the effectiveness of the additives to be determined in reducing odour threshold, gas and solids concentrations and maintenance of nutrients and micronutrients. It is believed that the results are more representative of what can be obtained in a commercial operation because the experiment tests the additives under continuous manure addition by pigs with no artificial mixing of the manure.

In the evaluation of odour threshold reduction effectiveness, trial 1 results suggested that ABC was able to provide a 11 to 31% odour threshold reduction, PB was able to provide 16 to 66% odour threshold reduction and WB was able to provide a 2 to 37% odour threshold reduction. The 66% reduction in odour threshold produced by PB was the only significant reduction in the experiment. Combined indoor trial data indicated that the ABC and WB additives were only capable of reducing odour thresholds to a small degree (4 and 11%) on Day 35.

Additive effectiveness based on gas production suppression illustrated in the mean H_2S concentrations from the first trial indicated that all of the additives were capable of producing relatively large reductions in the range of 14 to 76% from Day 35 to 63. These reductions were at both high and low levels of control H_2S. Mean H_2S concentrations from both indoor trials indicated that none of the additives reduced H_2S on Day 28, but all reduced H_2S by 57 to 76% on Day 35. Regarding NH_3 concentrations in the combined

indoor trials, all of the additives provided reductions. ABC produced the largest reduction on Day 35 (33%) and WB provided the most consistent reduction (18%).

Additive effectiveness relating to a reduction of total solids, a solubilization of solids and a reduction of total volatile solids was fairly conclusive. In this experiment none of the additives produced practical reductions in TS that could have improved manure-handling ease. Likewise, the additives provided little or no solubilization above the levels observed in the control. The only indication of solubilization was with the WB product, but the amounts were fairly limited. Both ABC and WB produced total volatile solids reductions. The data appeared to indicate that the reductions produced by WB may have been via solubilization and by ABC via gas emissions. Overall, little or no benefit was observed regarding solids fractions in the manure, so these additives would not be recommended if these benefits were a major objective of application.

Perhaps the strongest attribute of all of the additives was the ability to maintain levels of macronutrients and micronutrients above the control levels. The ABC additive produced TKN levels 16 to 19% higher than the control for the entire experiment while slightly smaller benefits were produced by PB and WB on Day 35. The ability of the additives to maintain nitrogen in the available form, especially on Day 35 represents a potential of 9 to 25% more nitrogen available during field application. Likewise, the 4 to 23% more P in the manure relative to the control levels increases the nutrient value of the manure as a fertilizer. Of equal importance was the additives' ability to maintain OPO_4 levels above the control levels during the indoor trial. Improvements in the nutrient value were observed in the K results. The ABC additive provided increases of 34%, WB of 17 to 21% and PB of 9 to 11%, relative to control levels. Another potential benefit that was observed was that additives increased levels of Cu and Zn relative to the control. These combined improvements suggest that use of the additives to improve potential crop yields when the manure is appropriately applied could be beneficial to the producer.

The results relating the additives' effectiveness based on ability to reduce waste strength was also quite conclusive. None of the additives were able to reduce COD levels relative to the control.

Recommendations and benefits

Overall, it appears that manure pit additives may provide some benefits to hog producers in all aspects except solids reductions and solubilization and waste strength reduction. Some control over the effectiveness of the additives may be gained by altering the retention time of the manure in the indoor channels to target the most desired improvements. However, the large variability means that it is difficult to conclusively confirm how additives will perform.

To make progress in pit additive technology, more basic, bench scale investigations are required to observe and understand the mode of action of additives. Such understanding will likely allow for more control in the variability of manure pit additive effectiveness.

Achievements, papers and presentation

The following materials have been developed as a result to this project as presented in the following list of reference.

Stinson, R., S.P. Lemay, E.M. Barber and T. Fonstad. 2000. Effectiveness of three manure pit additives in commercial scale manure channels and simulated outdoor storage. Poster and Banff Pork Seminar proceedings: Advances in Pork Production, Vol. 11, Abstract #30. Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, AB, Canada.

Stinson, R., S.P. Lemay, E.M. Barber and T. Fonstad. 1999. Effectiveness of three manure pit additives in commercial scale manure channels and simulated outdoor storage. ASAE Paper No. 99-4150. St. Joseph, MI: ASAE.

Stinson, R., S.P. Lemay, E.M. Barber and T. Fonstad. 1999. Odour and gas concentrations from swine manure treated with pit additives in commercial scale manure channels and simulated outdoor storage. Proceeding of the Manure Management '99, June 22-25, Saskatoon, SK, Canada.

Stinson, R., S.P. Lemay, T. Fonstad and E.M. Barber. 1999. A method for evaluating manure pit additives in manure channels and simulated outdoor lagoons. Poster and Banff Pork Seminar proceedings: Advances in Pork Production, Vol. 10, Abstract #21. Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, AB, Canada.

This project and the results obtained have also been presented to producers in Saskatchewan and Manitoba through Prairie Swine Centre Inc. communication activities.

PERSONNEL

Stéphane P. Lemay was the project coordinator responsible for overseeing the project activities. Part of his salary (333.33/month) was charged against the project for his participation.

Ryan Stinson was a master's student directly responsible for setting up and carrying out the experimentation, receiving $500.00/month to supplement his scholarship, for his contribution to this project.

Rob Fengler contributed as a Engineering Research Technician, providing assistance during room preparation and sampling events. He has spent 572 hours on the project.

EQUIPMENT

A sampling apparatus was designed and built for completing odour and gas sampling. It is essentially a pair of stainless steel manifolds that can be attached to the pulmonary pumping box for drawing air samples.

A set of 16 simulation lagoons constructed of durable plastic with a storage capacity of 3000 L (cattle waterers) was purchased for the outdoor evaluation phase of the project.

A submersible sewage pump was purchased and used for transferring manure during indoor and outdoor phases of the project.

PROJECT DEVELOPED MATERIALS

See the document in Appendix A.

PROJECT PHOTOS

No picture is provided as none seems practical.

ACKNOWLEDGEMENTS

Acknowledgement of ADF's financial contribution to this project was recognised in the following presentation and publication:

- Sphere '97 conference in Saskatoon
- Two University of Saskatchewan, Division of Environmental Engineering research day seminar/poster series
- Posters presented at the 1999 and 2000 Banff Pork Seminar
- ASAE Paper No. 99-4150 and presentation at the International ASAE meeting in Toronto July 1999
- Presentation at the Manure Management Symposium, Saskatoon, June 1999.
- Pork producers meetings realised by PSCI in Saskatchewan in February 2000 and in Manitoba in March 2000.

APPENDIX A

Effectiveness of Three Manure Pit Additives in Commercial Scale Manure Channels and Simulated Outdoor Storage

R. Stinson[1], S.P. Lemay[1], E.M. Barber[2] and T. Fonstad[3]

[1]Prairie Swine Centre Inc., P.O. Box 21057, 2105 - 8th St. East, Saskatoon, SK S7H 5N9; [2]College of Agriculture, University of Saskatchewan, Saskatoon ,SK S7N 5A9; [3]Department of Agricultural & Bioresource Engineering, University of Saskatchewan, Saskatoon ,SK S7N 5A9
Email: lemay@sask.usask.ca

The effectiveness of three manure pit additives was evaluated in commercial scale channels and simulated outdoor storage with grower-finisher pig manure. The additives were American BioCatalysts, Pit Boss and Westbridge (H4-5O2). Two trials were conducted, one consisted of an indoor phase followed by an outdoor phase and the second trial had only an indoor phase. Results from the two indoor phases were combined to provide eight replicates for statistical evaluation. Overall, the performances of the additives were quite mixed. Odour threshold reductions ranged from no reduction to 11% reduction during the indoor phase and no reduction to 66% reduction during the outdoor phase. Hydrogen sulphide concentrations were reduced from 57 to 76% and ammonia concentrations were reduced by 5 to 33% during the experiment. All of the additives seemed unable to achieve much solids reduction or solubilisation during the indoor phase of the experiment, but improving nutrient retention and availability was a strength of all of the additives. Nitrogen content and availability was improved by 7 to 19% and 9 to 25%, respectively during the indoor trial. Similarly, phosphorous availability was increased from 16 to 24% by the additives during the indoor phase. The additives did not perform very well in reducing chemical oxygen demand, providing no reduction or a minor reduction during the indoor phase. In general, the additives provided some benefit but were not able to improve all aspects of the manure.

Implications:
The tested pit additives would provide very limited odour and solids reductions with swine manure. They would tend to increase the manure nutrient value, which is an asset in areas where it can be used as a fertiliser. In-barn evaluation of manure pit additives is a valuable process to determine their effectiveness on a commercial basis and provides objective information on those products to the swine industry.

Advances in Pork Production (2000) Volume 11, Abstract #30

Development of Canola Oil for D

S.P. Lemay[1], E.M. Bart

[1]Prairie Swine Centre Inc.(PSCI), P.O. B
Agriculture, University of Saskatchewan,
7805 Stn Main, Saskatoon, SK S7K 4R5
Email: lemay@sask.usask.ca

A sprinkling system using un
dust levels in pig buildings.
system with off-the-shelf n
recommended oil application
experiments. Six different t
laboratory experiment to iden
promising nozzle was selecte
installed in one grower-finishe
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capabilities. Using recomme
sprinkling system provided
compared with a non-treated r
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80%, respectively. The sys
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swine buildings with undiluted
operation.

Implications:
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more pleasant environment ir
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and requires minimal labour fo

Advances in Pork Production (2000)

Effectiveness of Three Manure Pit Additives in Commercial Scale Manure Channels and Simulated Outdoor Storage

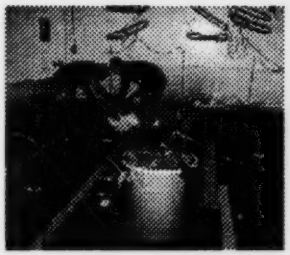
R. Stinson[1], S.P. Lemay[1], E.M. Barber[2], T. Fonstad[2]
[1]Prairie Swine Centre Inc., [2]University of Saskatchewan
Saskatoon, Saskatchewan, Canada

The Message

- Three manure pit additives, American BioCatalysts, Pit Boss and Westbridge, were tested in commercial scale manure channels and simulated outdoor storage.
- Odour threshold reduction ranged from 0 to 11% for the indoor phase and from 0 to 66% after the outdoor storage phase.
- The additives provided some benefits but were unable to improve all aspects of the manure.

Introduction

- Pit additives should desirably:
  - ✓ reduce nuisance odour
  - ✓ reduce manure pit gas emission
  - ✓ improve solubilization and reduce solids
  - ✓ retain nutrients and micronutrients
  - ✓ reduce manure strength
- Additives testing should represent commercial pig production conditions:
  - ✓ full scale channels
  - ✓ manure addition by pigs
  - ✓ no manure mixing



Air sampling set up during indoor trials

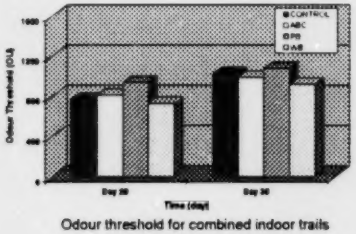
Objectives

- To evaluate the effectiveness of three manure additives in reducing odour threshold, gas concentrations, solids and manure strength and in maintaining nutrient and micronutrient content.

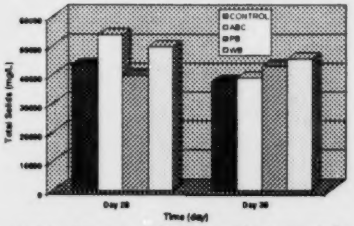
Experimental Set Up

- Three additives:
  - ✓ ABC (American BioCatalysts : bacteria and enzymes)
  - ✓ Pit Boss (PB : copper sulfate mixture)
  - ✓ Westbridge (WB : organic amendment)
- Indoor trials:
  - ✓ 2 room cycle :, 8 replicates per additive
  - ✓ 3 weeks of manure accumulation,
    2 weeks of pretreatment and 5 weeks of treatment
  - ✓ Air and slurry samples on weeks 4 & 5
- Outdoor trial:
  - ✓ plastic tubs simulating lagoons, 4 replicates per additive with manure from the first indoor trial
  - ✓ Air and slurry samples taken after 4 weeks of storage
- Parameters evaluated:
  - ✓ Air: odour threshold, CO_2, NH_3 and H_2S levels
  - ✓ Manure: solids, nutrients, micronutrients and COD

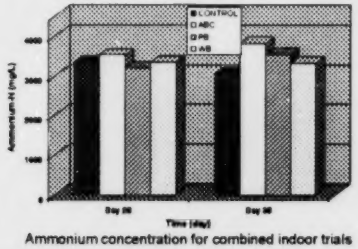
Results



Odour threshold for combined indoor trails



Total solids concentration for combined indoor trails



Ammonium concentration for combined indoor trials

Conclusions

- Odour threshold was reduced by:
  - ✓ 0 to 11 % for indoor trials
  - ✓ 0 to 66% for outdoor trial
- No additive had an impact on solid reduction or solubilization.
- All the additives had a positive impact on nutrient retention and availability.

Acknowledgements

Saskatchewan Agriculture and Food (ADF)
American BioCatalysts
Chem-A-Co International
Westbridge
Strategic program funding provided by:
SaskPork, Alberta Pork, Manitoba Pork

Paper No. 994150
An ASAE Meeting Presentation

EFFECTIVENESS OF THREE MANURE PIT ADDITIVES IN COMMERCIAL SCALE MANURE CHANNELS AND SIMULATED OUTDOOR STORAGE

by

R. Stinson[1] Graduate Student
S.P. Lemay[1] Research Scientist-Engineering
E.M. Barber[2] Dean of Agriculture
T. Fonstad[2] Assistant Professor

[1]Prairie Swine Centre Inc., P.O. Box 21057, 2105 – 8th Street East, Saskatoon, SK, Canada S7H 5N9
[2]University of Saskatchewan, Saskatoon, SK, Canada S7N 5A8

Written for Presentation at the
1999 ASAE Annual International Meeting
Sponsored by ASAE

Sheraton Centre Hotel
Toronto, Ontario Canada
July 18-21, 1999

Summary: The objective of this experiment was to evaluate the effectiveness of three pit additives in commercial scale manure channels and simulated outdoor storage. The additives were American BioCatalysts, Pit Boss and Westbridge (H4-5O2). Two trials were conducted, one (Trial 1) consisted of an indoor phase followed by an outdoor phase and the other Trial (2) had only an indoor phase. Results from the two indoor phases were combined to provide eight replicates during statistical evaluation. Compared to many other testing protocols, this protocol possesses many strengths, including commercial scale evaluation, increased repetitions and natural variations in manure composition. Overall, the performances of the additives were quite mixed. Odour threshold reductions ranged from no reduction to 11% reduction during the indoor phase and no reduction to 66% reduction during the outdoor phase. Hydrogen sulphide concentrations were reduced from 57 to 76% and ammonia concentrations were reduced by 5 to 33% during the experiment. All of the additives seemed unable to achieve much solids reduction or solubilization during the indoor phase of the experiment, but improving nutrient retention and availability was a strength of all of the additives. Nitrogen content and availability was improved by 7 to 19% and 9 to 25%, respectively during the indoor trial. Similarly, phosphorous availability was increased from 16 to 24% by the additives during the indoor phase. The additives did not perform very well in reducing chemical oxygen demand, providing no reduction or a minor reduction during the indoor phase. In general, the additives provided some benefits but were not able to improve all aspects of the manure.

Keywords: Manure pit additive, Odour, Gases, Solids, Nutrients

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EFFECTIVENESS OF THREE MANURE PIT ADDITIVES IN COMMERCIAL SCALE MANURE CHANNELS AND SIMULATED OUTDOOR STORAGE

R. Stinson, S.P. Lemay, E.M. Barber and T. Fonstad

INTRODUCTION

Today, odour control is a primary concern of the swine industry. In some cases, public perception of odour as a nuisance has given swine production a bad reputation. To remedy this perception, efforts have focused on controlling odour at various stages of production. These efforts are usually successful in suppressing odour production, and while suppressing odour production may be a good short-term solution, nuisance odour still remains a problem at a later point in production. To complicate the issue, producer's attempts to locate or expand their operations have been blocked by legal action based on odour complaints. In these cases, opponents are typically neighbours or nearby communities that have heard about or experienced the nuisance odour. Publicity from such cases has been costly to producers both socially and economically. For this reason, many companies have developed manure pit additives in order to control odour. If effective, these products would be a great benefit to the swine industry, easing some of the controversy surrounding the odour issue.

In addition to odour, other issues regarding manure are becoming more of a concern. These other issues include manure handling ease, manure pit gas production, nutrient and micronutrient retention and waste strength. Manure pit additive manufacturers claim to address these concerns by reducing and solubilizing solids content, suppressing pit gas production, conserving nutrients and reducing waste strength. For any single treatment to be adequate, the additive would need to improve on most or all of these issues and apply to all aspects of manure production. Although, improvements in any one of these areas may be all that is required depending on the circumstances at any individual production site.

In the past, most manure pit additive evaluations were not conducted independently of the manufacturer, so some questions as to the validity of the results were present. As of late, more of the evaluations are being carried out by independent testing facilities, removing some of the doubt that may have been present in the past However, most of the testing has been carried out on a bench scale, which may not adequately characterize the effectiveness of additives in actual barn applications. Many inconsistencies between commercial and bench-scale conditions exist. Bench-scale evaluations do not always correctly represent commercial surface area to depth ratios, manure additions are infrequent compared to barn conditions and manure is commonly homogenized (mixed) which does not occur to this extent in the actual manure channels. Moreover, the differences between bench-scale protocol and actual barn conditions introduce some question regarding the performance of the additives on a commercial scale when using bench-scale results as indicators.

A factor of many of the experiments that may also contribute to some of the mixed reviews of additives is the limited number of replications that have been conducted. Limited replication combined with large amounts of variation in manure composition can produce results with

minimal statistical power. Still, the hog producers that use these products are looking for results not statistical significance.

Recent studies suggest that some progress has been realized with the application of manure pit additives. In a study conducted by Zhu et al. (1997) all five additives tested (MPC, Bio-Safe, Shac, X-Stink and CPPD) reduced odour concentration by 58 to 87%, as determined through dynamic triangle forced-choice olfactometry. In the same experiment, only MPC was capable of producing a significant TS reduction and Bio-Safe produced significant increases in NH_4-N levels. Lorimer (1996) also reported on results from the experiments conducted by Zhu and Bundy, which indicated that none of the additives reduced TS significantly, but some were observed to promote elevated NH_4-N levels. In another experiment, eight products (Bio Charge, Roebic Deod, Pit Boss, Shac, Bio-409, MS-4, Pit Stop and Deo Odorase) were evaluated in full-scale rooms, resulting in odour reductions of 5 to 48% and NH_3 reductions of 42 to 51% (AURI 1997). The AURI study also indicated that the additives produced significant increases in P relative to control and small increases in NH_4-N. Two (NX23 and BioSuper) of the five additives tested by Martinez et al. (1997) reduced NH_3 emissions by 40 to 50%. Heber et al. (1997) reported reductions of NH_3 emissions from 1.8 to 5.9 g/day-pig and small decreases in overall NH_3, H_2S and CO_2 concentrations. Out of the seven additives (Agri-Scents, Biosurge, Hydrogen cyanamide, Micro-Aid, Natural Odor Catalyst, Sphagnum peat and Roebic) evaluated by Patni and Jui (1993), five additives significantly reduced NH_3 concentrations and three significantly reduced H_2S concentrations. Successful application of acid treatments and sphagnum peat moss reduced losses of NH_3 by 74.6% (Al-Kanani 1992).

Many of these evaluations were carried out on a bench scale (Zhu et al. 1997; Patni and Jui 1993; Al-Kanani 1992) that may not represent actual commercial conditions adequately for testing purposes. As a result, it was suggested that this manure additive testing protocol be performed in commercial-scale manure channels and simulated outdoor storage. By carrying out the experiment in this manner, the results may be more indicative of what might be expected by hog producers when the additives are applied in their production facilities.

OBJECTIVE

The objective of this research was to evaluate the effectiveness of three manure pit additives to reduce odour threshold and gas concentrations above the manure surface and reduce solids and waste strength, and maintain nutrient and micronutrient content in the manure. in commercial-scale manure pits and simulated lagoons. To do so, different analyses were made in two phases of the experiment, the indoor phase (manure channel) and the outdoor phase (simulated lagoon) representing the stages of manure storage while it is at the production facility. This experiment proved to be an exhaustive evaluation of many manure characteristics and as such, only the most pertinent data are presented in this paper.

MATERIALS AND METHODOLOGY

Experimental Design and Protocol

The indoor experiment was carried out in a commercial production room at Prairie Swine Centre Inc (PSCI). The room was modified to accommodate the experiment. Within the room, 16 manure channels, arranged in groups of four under each of four pens were used to conduct the experiment. In each block of four manure channels, each additive was applied in one of the channels and one channel was kept as a control. Two indoor trials were conducted providing eight replications of each additive. In preparation for the experiment, the fully slatted room was power-washed, the manure channels were drained and power-washed, the slatted flooring was replaced and pens were constructed. A feeder and bowl waterer was positioned over each manure channel, to standardize feed and water wastage. Figure 1 is a sketch of the experimental room configuration.

To begin the trials, 36 pigs with a mean weight of 28 kg were placed into each of the four pens, and were fed *ad libitum* for the duration of the experiment. Each trial consisted of three phases: an accumulation phase, a conditioning phase and a treatment phase. The accumulation phase lasted for three weeks, where all of the manure that was produced was left untreated in the manure channels. In the following two weeks (conditioning phase) intended to simulate continuous barn operations, manure accumulated and was treated with the additives at recommended rates. At the end of the conditioning phase, the manure channels were drained by gravity. In the following treatment phase, manure accumulated and was treated at recommended rates for five weeks. On Days 28 and 35 of the treatment phase, air samples were collected above the manure surface and slurry samples were then removed. After the fifth week of the first indoor trial, manure was transferred outdoors to simulated lagoons to begin the outdoor trial.

The outdoor trial was conducted in 16 plastic containers intended to simulate storage lagoons, situated in a staggered line, running west to east. The simulated lagoons were 1,360 L (1.83 m diameter x 0.56 m high) plastic cattle waterers. For the outdoor experiment, the manure was not treated with the additives after being transferred. The manure remained in the lagoons for four weeks and air and slurry samples were taken on Days 49 and 63, in the same manner as the indoor trials.

Additives

The additives that were evaluated in this experiment were American BioCatalysts (ABC), Pit Boss (PB) and Westbridge (WB). The ABC additive is a combination of enzymes and microbes intended to breakdown manure constituents both chemically and biologically. PB is an acidified copper sulphate mixture, believed to react chemically and electrically with complex slurry components. The WB additive is an organic amendment intended to increase microbial activity and oxidize organic components of manure. Frequency and rates of additions used in the indoor experiment were as follows:

ABC: ABC 100E and preactivated ABC 200M at 1:100,000 on initial addition and 1:500,000 every two weeks.

PB: adjustment of manure pH to 7.0 then applied at 1:60,000 of final manure volume.

WB: applied at 1:100,000, based on daily manure production rates.

Air Sampling and Measurements

Indoor and outdoor air samples were taken with a pulmonary pumping system illustrated in Figs. 2 and 3, respectively. Quarter-inch stainless steel tubing and stainless steel three-way valves were used in the manifold and tubing system to reduce interactions between the sampling system and the air sample. Samples were collected in 10-L Tedlar bags to provide a large enough volume for olfactometry measurements and to reduce interactions between the air sample and the bag. By using the pulmonary pumping system, the air sample did not come into contact with the Gilian AirCon-2 air sampler (Gilian Instrument Corp., W. Caldwell, NJ, USA).

Before sampling, each manure channel was isolated by covering the surface with polyethylene secured to the floor with 2x4 studs (indoor) and each simulated lagoon was isolated with a sheet of plywood (outdoor). By isolating the manure, air samples would not be contaminated with air from outside the manure channel or simulated lagoon. After isolating each manure channel or simulated lagoon, the manifold of the air sampling system was lowered to 5 cm above the surface of the manure in three locations. Before sampling, the line was purged for 1 min at a flow rate of approximately 2 L/min. Then, the air sample was taken at a flow rate of approximately 2 L/min for 5 min. Two samples were taken from each manure channel or lagoon, one for odour threshold analysis and the other for gas concentration determination.

Odour detection thresholds reported in odour units (OU) were determined within 48 hours by triangular forced-choice dynamic olfactometry at the Alberta Research Council in Vegreville, Alberta. Gas (H_2S, NH_3 and CO_2) concentrations reported in ppm were determined with colorimetric detection tubes (Matheson Gas Products, Secaucus, NJ, USA).

Slurry Sampling and Measurements

Slurry samples were also taken on Days 28 and 35 of the treatment phase during the indoor trials and Day 63 of the outdoor trial. For each manure channel or lagoon, a composite slurry sample was taken by combining subsamples from three positions throughout each manure channel. These positions were 2 m from the waterer end, the middle, and 2 m from the feeder end. This arrangement of samples was chosen because manure in these locations could be quite different in composition due to feed and water spillage. The subsamples were obtained with a clean 10-L plastic pail. Subsamples taken from all three locations were combined in a clean plastic container and briefly stirred with a clean plastic rod. Then the samples were transferred into 500-ml plastic jars and sent to NorWest Laboratories in Winnipeg, Manitoba for analysis. All sampling materials were thoroughly cleaned with water to remove the possibility of cross contaminating future samples. Slurry sampling was carried out after air sampling to avoid manure agitation that could affect air samples.

A number of analyses were carried out to characterize solids content, nutrient and micronutrient levels, strength and physicochemical characteristics of the slurry samples. Determinations of

total solid, total suspended solid, total dissolved solid and total volatile solid concentrations were used to evaluate additive effects on solid fractions in the manure. Macro- and micronutrient contents that were investigated included Total Kjeldahl nitrogen, ammonium-nitrogen, phosphorous, ortho-phosphorous, potassium, copper, zinc, magnesium and sodium. Chemical oxygen demand was measured as an indicator of additive effect on waste strength. The parameters that are presented in this paper include total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), total volatile solids (TVS), Total Kjeldahl nitrogen (TKN) ammonium-nitrogen (NH_4-N), phosphorous (P), ortho-phosphorous, potassium (K), copper, zinc and chemical oxygen demand (COD).

Statistical Design and Analysis

The indoor experimental design consisted of two trials (summer and fall, 1998) of a balanced 4x4 latin-square, with the two controlled effects: additive (n=4) and manure pit position in block (n=4). Additives were designated to manure channels such that each additive occurred in each pen once, and occupied each manure pit position once. The outdoor trial experimental design was a randomized complete block design.

All of the data were analyzed using the GLM procedure in SAS (Version 6.1 for Windows). Due to missing data, least-square means (LSMEANS) analysis was the most appropriate method for determining additive means. All comparisons between additive means were made using a pair-wise t-test (LSD) with a significance level of $P<0.05$.

During the experiment some problems during the transfer of the manure from indoor manure channels to outdoor storage were encountered. The procedure produced unreliable results for the majority of parameters on Days 49 and 63. The only exceptions being odour threshold and H_2S concentrations. These sets of data are still presented here but as a result of the transfer problems, a great deal of caution should be used when interpreting these results.

RESULTS AND DISCUSSION

Odour Threshold

Odour threshold measurements from Trial 1 and the combined indoor trials (1 and 2) are presented in Tables I and II, respectively. Differences between additive means in Trial 1 were only significantly different ($P>0.05$) on Day 63, based on statistics carried out on log transformations of odour thresholds. The control mean odour threshold was highest on Day 28 (1,030 OU), stabilizing until Day 49 at (1,010 OU) and finally falling to 680 OU on Day 63. This indicated that the majority of the odour emission during this relatively hot period of time occurred in the manure channels with some dissipation in the lagoons. The dissipation may have resulted from the transfer problem encountered between the indoor and outdoor trial.

ABC additive was the most consistently effective additive during the indoor portion of the trial, reducing the odour threshold relative to control in the range of 11 to 16%. The levels of 870 and 900 OU measured on Days 28 and 35, respectively, were the lowest of any of the additives on any of these days. In the outdoor portion of the trial, ABC was not very effective on Day 49 resulting in an odour threshold higher than the control, but on Day 63, ABC performed better,

providing a 31% reduction. The reduction produced by ABC on Day 63 was the smallest of any of the additives. PB additive did not produce any odour reductions in the indoor portion of the trial, but produced the greatest reductions in the outdoor experiment. These reductions were 16 and 66% lower than the control thresholds on Days 49 and 63. The 66% percent reduction was the only reduction that was statistically ($P>0.05$) lower than the control in the entire experiment. WB additive also produced good odour threshold reductions in the outdoor experiment (9 and 37%), but did not produce any substantial reductions in the indoor trial.

In terms of the first indoor trial, ABC produced the best overall odour threshold reduction. This suggests that the microbial and enzymatic activity of ABC is the best option for odour threshold reduction in the indoor manure channels. In terms of the outdoor portion of the first trial, both PB and WB additives produced good odour reductions. In the simulated lagoons, the chemical activity of the PB additive appeared to be slightly better than the habitat enhancement of WB, in suppressing odour production.

When data from both indoor trials were combined (Table II), differences between additive odour threshold means were not statistically significant ($P>0.05$) and the variation within a means are very large. The control odour threshold was 770 OU on Day 28 and rose to 1,030 OU on Day 35. On Day 28, WB was the only additive able to produce a minor (5%) odour threshold reduction, although this reduction is of little practical significance. Both ABC (810 OU) and PB (940 OU) did not provide any reduction in odour threshold at that time. These results indicated that application of these additives does not provide any real benefit at Day 28. The same can be claimed of the additives' ability to reduce odour emissions on Day 35. On Day 35, ABC and WB were able to produce small (4 and 11%) odour threshold reductions, but these reductions are of little practical value. PB (1080 OU) was the least effective on Day 35 either, resulting in an odour threshold that was 5% higher than the control.

Overall, it is unlikely that small improvements observed with ABC and WB additives represented either a beneficial or a detrimental effect. Whereas, the 22% increase in odour threshold produced by the PB additive likely represented a noticeable difference. In general there is too much variation in the odour threshold results to provide a statistical analysis with the ability to separate means with smaller differences.

When comparing odour thresholds with gas and solids concentrations from this experiment, strong correlations were not found that could indicate that changes in gas or solids concentrations resulting from treatment had an effect on odour threshold.

Hydrogen Sulphide

Table I illustrates mean hydrogen sulphide concentrations from Trial 1, and the combined indoor trials (1 and 2) results are presented in Table II. Data from Trial 1 suggest that none of the additives were able to reduce H_2S concentrations relative to control on Day 28, but by Day 35, all of the additives produced some very good reductions. The reductions ranged from 57 to 76% indicating that the action of the additives was quite effective in suppressing the sulphur metabolism that contributes to H_2S evolution. This improvement appears to be a combination of the additives' ability to reduce H_2S emissions and the natural tendency for increased H_2S production in the control. On Day 49, the H_2S concentrations for all of the additives and the control spike up many times greater than the corresponding Day 35 concentrations. Many factors

may have contributed to these increased concentrations. They might include increased temperature in the outdoor storage lagoon and partial homogenization during the transfer protocol. Once, again, caution should be advised when viewing Day 49 and 63 results. On Days 49 and 63, all of the additives produced reductions in H_2S concentrations in the range of 14 to 76%. From Day 35 on, ABC and PB appeared to lose some of their ability to suppress H_2S emissions while WB maintained a consistent level of reduction.

Overall, all of these reductions are fairly substantial on Days 35, 49 and 63, but in general the levels are also very low compared to the colorimetric tube detection limit. The low control concentrations of H_2S on Days 28, 35 and 63 also indicate that reductions produced by the additives may not have been necessary to reduce health and emission concerns, but the continued suppression on Day 49 indicates that the additives were also effective at higher levels of H_2S.

Means from the combined indoor trials concurred with Trial 1 findings. The variation in concentrations, indicated by relatively large LSD values, is quite large. These large variations in H_2S concentrations were consistent with large variations observed in odour threshold and NH_3 concentration. On Day 28, none of the additives were able to reduce the H_2S concentration relative to control. Then on Day 35, all of the additives reduced H_2S in the range of 57 to 76%, representing substantial reductions. These findings suggest that the additives would be a benefit to producers by reducing health risks and emissions at the later stages of manure accumulation (Day 35) in the manure channels.

Ammonia

Combined data from the two indoor trials indicated no significant differences ($P>0.05$) between additive means (Table II). The large LSD values relative to the control mean indicates large degrees of variability in NH_3 measurements. Control concentrations of NH_3 were 12.4 and 14.9 ppm on Days 28 and 35. These concentrations were not very high and do not pose any serious health or emission concerns. The ABC additive produced a slight reduction (6%) in NH_3 concentration on Day 28 and a 33% reduction on Day 35. This suggests that the action of ABC increased with time. PB also produced a slight reduction (5%) in NH_3 concentration on Day 28, but failed to result in a reduction on Day 35. The reductions produced by PB were much lower than the reductions of approximately 50% reported by AURI (1997). WB additive provided reductions of approximately 18% on both sampling days. This was the most consistent reduction illustrating that the merit of the habitat enhancement may be improved reliability.

These findings indicate that all of the additives were able to suppress some NH_3 volatilization through their different modes of action. Overall, ABC produced the best NH_3 concentration reduction on Day 35 but WB produced the most consistent reductions. Ultimately, these reductions would be of little consequence because the control concentrations were very low, representing small potential emissions.

Total Solids

One goal of treatment is to improve manure-handling through reduction of TS in the manure. Table III summarizes the mean TS concentrations determined in the combined indoor trials. Control TS levels dropped from 43,200 to 37,300 mg/L from Day 28 to 35. This may indicate that either the natural microbial consortium was producing TS reductions or that TS reduced as a

function of increased dilution of the manure with time. On Day 28, PB produced the only decrease (8%) in TS relative to the control. In fact, this was the only decrease produced by any of the additives during the entire indoor experiment. Despite, being the sole reduction, an 8% reduction does not likely represent a noticeable difference in manure-handling ease to the producer. Both WB (14%) and ABC (24%) had TS concentrations higher than the control on Day 28. On Day 35, none of the additives were able to produce a reduction in TS relative to the control. However, on Day 35, ABC (4%) performed the best of any of the additives, while PB (15%) and WB (21%) showed reduced ability to reduce TS compared to the control. This might suggest that the microbial and enzymatic activity of the ABC additive was beginning to increase solids breakdown and the chemical activity of the PB additive was beginning to diminish.

Overall, the additives did not provide any substantial benefit in terms of TS reduction. The only reduction was produced by PB on Day 28, which was a fairly small reduction that would not likely improve manure-handling ease considerably.

Total Suspended Solids and Total Dissolved Solids

In addition to solids breakdown, manure-handling ease may also be improved by solubilizing solids. To evaluate the effectiveness of the additives at solubilizing the solid fraction of the manure, both TSS and TDS levels were determined (Table III). Effective solubilization was represented by a transformation of TSS to TDS in the manure. Neither TSS nor TDS results had significant differences ($P>0.05$) between additive means. For TDS data on Day 28, trial was found to be statistically significant ($P>0.05$) with the second trial larger than the first. The increased solubility does not seem to stem from environmental conditions like temperature as the temperature was lower in the second trial than the first. If temperature had influenced TDS results, the first trial with the higher temperature should have resulted in more solubilization.

Regarding TSS, the trend displayed by the control was an increase on Day 35 (33,400 mg/L) from the level on Day 28 (28,500 mg/L). This was accompanied by a decrease in TDS on Day 35 (9,000 mg/L) from the level on Day 28 (9,700 mg/L). This combination of increasing suspended solids and decreasing dissolved solids indicated that solubilization was not a natural tendency in the untreated manure.

ABC additive did not appear to successfully solubilize solids relative to the control. Results indicated elevated TSS levels combined with elevated TDS levels compared to the control on both sampling days. The elevated TDS levels were indicative of increased solubilization but the elevated TSS levels reduce the impact of the solubilization. This suggests that the microbial and enzymatic activity of the additive was unable to promote the conversion of TSS to TDS at a level greater than the control.

PB additive resulted in lower levels of TSS (46%) and TDS (9%) relative to control on Day 28, but increased to 34,800 and 10,300 mg/L of TSS and TDS respectively on Day 35. This indicates that the additive was more effective on Day 28 than Day 35. Perhaps the effectiveness of the additive diminished with time because it was only added once at the very beginning of the trial.

WB additive reduced TSS, in combination with increased TDS levels from day 28 to 35. On Day 28, WB did not perform better than the control but was however much better than the control on

Day 35. On Day 35, TSS was reduced by 19% and TDS was increased by 39%. This combination indicated that WB was the only additive able to provide beneficial solubilization.

Total Volatile Solids

The TVS fraction is the fraction of solids that can contribute to odour and gas production. The additive effect was not found to be significant ($P>0.05$) in terms of differences between additive means (Table III). Control manure was observed to decrease in TVS throughout the experiment indicating that the volatile fraction of solids was either being solubilized or converted into gas and released to the atmosphere. As solubilization was quite low in the control, it was likely released to the atmosphere.

A similar tendency was also observed in the ABC and WB treated manure, with the decrease associated with ABC being far more dramatic. ABC levels dropped from 41,800 to 27,200 mg/L and WB dropped from 38,600 to 34,200 mg/L. In light of these additives' performances relating to solids solubilization and gas production, it is likely that WB, but not ABC, were solubilizing volatile solids rather than converted into gaseous emissions. Still, the interpretation of these results must be made with caution because determining whether reduced TVS levels in ABC and WB treated manure represented a decrease in odour and gas production potential or a release in the form of gas is difficult. PB additive maintained a fairly stable level of TVS throughout the experiment.

Considering the overall effect of the additives on solids, it was apparent that none of the additives provided much solids reduction and only WB provided some solubilization. As solids reduction is likely one of the main reasons for using the additives, these additives may not provide much of this type of benefit.

Total Kjeldahl Nitrogen

The two nitrogen fractions that were analyzed were TKN and ammonium, representing total oxidizable forms of nitrogen and the plant available form, respectively. Total Kjeldahl Nitrogen measurements indicate no statistically significant differences ($P>0.05$) between additive means (Table IV). Control TKN levels in the manure decreased with time, from 5,270 (Day 28) to 4,970 mg/L (Day 35). This indicated that a 28-day retention time may provide the best nitrogen retention if the manure was untreated, because nitrogen metabolism appeared to increase with time. Increased nitrogen metabolism could result in losses of nitrogen in volatile forms. Control TKN values were 2 to 3 times higher than TKN measurements reported in previous experiments (Lorimer 1996).

A decline in TKN was also observed in ABC additive results from Day 28 to 35. This decline did not adversely affect the nitrogen retention associated with the additive. In spite of the losses, ABC had the highest levels of TKN on both days, with levels 16 to 19% greater than the control. This suggests that the enzymatic and microbial activity of ABC remained quite active in retaining nitrogen for the duration of the experiment. This also indicates that ABC treatment does not require a specific retention time to provide nitrogen retention.

Neither the WB nor PB additive displayed TKN levels higher than the control on Day 28 but both increased in TKN from Day 28 to 35. These TKN levels were maintained at 7% (WB) and 13%

(PB) higher than the control on Day 35. This indicates that the chemical and habitat enhancement activity of these additives was only beneficial when the control manure began to lose TKN. To improve the effectiveness of the additives using management strategy, both PB and WB seem to require a 35-day retention time to provide TKN retention.

Ammonium-Nitrogen

Ammonium-nitrogen represents a valuable resource when manure is applied as a fertilizer. Therefore, an effective treatment should produce higher levels than control manure. Table IV summarizes the mean NH_4-N concentrations from the combined indoor trials. The available nitrogen (NH_4-N) in the control manure was observed to decrease from 3,350 (Day 28) to 3,060 mg/L (Day 35). This decrease is quite small and may be a function of dilution or losses via NH_3 volatilization. On Day 28, the only additive that was able to maintain nitrogen in its available form at a level greater than the control was ABC. However, the improvement produced by ABC was only 5% greater than the control, which does not represent a major improvement. WB was only able to maintain the same amount of nitrogen in the NH_4-N form while PB manure had 5% less than the control.

On Day 35 all of the additives appeared to have produced measurable improvements regarding NH_4-N levels. ABC was still the best of the additives producing 25% higher levels than the control, PB was next best at 16% and WB was able to promote 9% more NH_4-N than the control. All of these results indicate that the additives were capable of making higher levels of nitrogen available at the 35 day sampling time. These elevated levels of available nitrogen represent a valuable asset in terms of nutrient application.

Overall, ABC was the best additive, but all of the additives were capable of providing real benefits by improving available nitrogen levels in the manure. This suggests that all of the modes of action utilized in the additives were capable of either converting more nitrogen into the NH_4-N form, suppressing NH_4-N release as NH_3 or a combination of the both. This ability was definitely one of the strengths of all of the additives that were evaluated.

Phosphorous

Phosphorous also represents a valuable resource that can be applied as a fertilizer. Means from the combined indoor trials are summarized in Table IV. Control levels of P in the manure dropped dramatically from Day 28 (2,010 mg/L) to Day 35 (1,190 mg/L). This decline can only be explained by a dilution effect with time or an inconsistent sampling strategy. On Day 28, all of the additives provided improvements in the overall P present. PB was the best with 23% more, WB was next best with 10% more and ABC had 6% more. These increased levels would be a valuable asset in terms of nutrient value when the manure was land applied as a fertilizer. The increases in P were maintained until the Day 35 sampling period, but the improvements were smaller for PB and WB than they were on Day 28. From Day 28 to Day 35, ABC was the only additive that was able to improve P maintenance relative to the control. On Day 35, ABC (12%) provided the best retention followed by PB (8%) and WB (4%). Overall, the maintenance of P above the control levels provided by the additives represents a potential benefit to the producer. The benefit will be realized in higher crop yields when the manure is properly used as a fertilizer.

Ortho-phosphate levels (Table IV), representing the plant available fraction, are perhaps more important than phosphorous measurements in terms of immediate fertilizer value. Similar to the phosphorous results, ortho-phosphate results indicated that the differences between additive means were not statistically significant ($P>0.05$). Control levels of ortho-phosphate on Days 28 and 35 were 660 and 453 mg/L, respectively. These values indicated that the control maintained approximately the same proportion of the total phosphorous in the plant available form on both sampling days.

The tendency for ortho-phosphate levels to decrease with time was present in the results representing the additives' performance. During the indoor trial, both WB and ABC were able to maintain ortho-phosphate levels at approximately 20% greater than the control. This indicates that the habitat enhancement and microbial and enzymatic action of the treatments improved the availability of phosphorous relative to the control, representing a valuable asset in terms of fertilizer value. Unlike the other additives, PB was unable to promote phosphorous availability relative to control on Day 28, resulting in a 3% decrease. However, on Day 35, the PB ortho-phosphate level had rebounded to a level about 16% higher than the control. Therefore, a 35-day retention period might be the best management strategy in terms of phosphorous retention when applying PB. These findings suggest that all of the additives were able to provide ortho-phosphate retention compared to the control, which is a positive effect in terms of nutrient value of the manure.

Potassium

Potassium is another essential nutrient, important in the fertilizer value of the manure. Analyses were carried out to determine the ability of the additives to maintain potassium levels higher than those observed under control circumstances (Table IV). On Day 28, differences between additive means were not significantly different ($P>0.05$) and on Day 35, ABC was significantly higher than the control. On Day 28, the control level was 2,220 mg/L and then it increased to 2,420 mg/L on Day 35. This indicates that potassium addition exceeded the dilution of the manure between the two sampling days.

ABC (2,970 mg/L), PB (2,470 mg/L) and WB (2,690 mg/L) levels were all higher than the control on Day 28. The potassium retention produced by all of the additives relative to control indicates that a 28-day retention period would provide elevated potassium levels. However, a 35-day retention period may prove to be even better than a 28-day retention time. Day 35 results suggest that all of the additives produce benefits in terms of potassium retention but only ABC retention was significantly greater than the control. Thus, the microbial and enzymatic action of the ABC additive was much more effective than the control and slightly better than the other additives. Overall, potassium retention appeared to be an area where all of the additives were able to provide some benefit.

In terms of overall nutrient retention and availability, all of the additives appear to be able to produce benefits. The added value of increased overall and plant available nutrients resulting from the application of the additives is definitely one of the strongest advantages to using them. This value is passed on to the producer in terms of increased value in the manure and potential increases in crop yields.

Copper and Zinc

Micronutrients in the manure are a valuable resource when manure is applied as a fertilizer, but can also exhibit toxic effects at high levels. The objective of micronutrient analysis was to determine if any of the additives were able to maintain micronutrient levels above control levels. The micronutrients considered in this experiment were copper and zinc. None of the differences between additive means representing copper or zinc concentrations (Table IV) were statistically significant ($P>0.05$).

The control maintained a fairly constant level of all micronutrients between Days 28 and 35. Copper and zinc levels were observed to have had a minor drop in concentration between the sampling days. This drop may have resulted from a dilution effect in the manure produced by decreasing amounts of the micronutrients entering the manure while solids and water remained constant over this seven-day period. Neither of these levels appeared to be in a harmful range for use as a fertilizer, and adopting either a 28 or 35 day retention period over the other option could derive little or no advantage.

The ABC additive maintained higher levels both of the micronutrients than the control on both sampling days. The copper level of 14.6 mg/L on Day 28 was the second highest of the additives and the 12.1 mg/L determined for Day 35 was the lowest. This indicates that a 28-day retention period may provide more copper during landspreading. Again, a 28-day retention period would have provided more benefit. Zinc levels in the ABC manure were highest on Day 28 (43.37 mg/L) falling to 36.60 mg/L on Day 35. This suggests that the 28-day retention time may be beneficial in terms of zinc as well. Overall, the action of the ABC additive appeared to be effective in maintaining micronutrient levels higher than the control level.

The PB additive was also reasonably effective in maintaining micronutrient levels higher than control, but a 35-day retention time appears to be a better management strategy. On Day 28, PB resulted in copper levels 12% greater than the control and then increased in the next seven days to 17% greater than the control. This may be a bit misleading because the actual concentration of the copper was higher on Day 28. Regardless, it is strange that the copper level in PB was lower than the other treatments, considering that the additive itself consists of copper. The amount of additive applied to the manure was very low which may have limited some of its effectiveness. Zinc levels also showed increases relative to the control levels from Day 28 to 35. The zinc levels rose from 9% less than the control to 3% greater than the control.

The WB additive provided excellent micronutrient retention, at a level greater than the other additives. The data also indicated that a 28-day retention period would be the best management strategy when using this product, in terms of increasing micronutrient content. Copper levels were 16.2 and 13.4 mg/L on Days 28 and 35 representing 31 and 17% increases relative to control. The previously mentioned copper levels and the zinc level of 45.30 mg/L on Day 28 were the highest of any of the additives, indicating that WB was the best additive in terms of maintaining these micronutrients at that point in time. This suggests that the habitat enhancement provided by the additive was better at preserving these micronutrients than any of the other additives. Overall, PB additive was likely the best additive in terms of micronutrient retention, especially if a 28-day retention strategy was adopted.

Regarding micronutrients, the overall performance of the additives is quite good. PB may be the least effective additive in retaining micronutrients while both ABC and WB are very comparable. In total, all of the additives were capable of producing positive retention of these critical manure components. Coupled with the effective nutrient retention and availability discussed in the previous section, the additives appear to provide a benefit in terms of fertilizer value.

Waste Strength

Chemical Oxygen Demand (COD) was determined from the manure, to be used as an indicator of the strength of the manure. To be considered beneficial, additive should produce reductions in COD levels. None of the differences between additive means in the experiment were statistically significant ($P>0.05$). Mean levels of COD are presented in Table IV. Control levels began at 38,800 mg/L on Day 28 and dropped to 33,000 mg/L on Day 35, indicating a natural tendency to decrease with time.

The ABC additive was able to produce a decrease in COD from Day 28 to 35, but these levels were both higher than the control. PB additive produced a minor reduction in COD on Day 28, but was unable to reduce COD on the subsequent sampling day. The decrease in COD of 5% on Day 28 was the only improvement relative to the control in terms of COD reduction. COD levels for WB indicate that WB provided the worst COD reduction of any of the additives on Day 28 and the second best on Day 35. Neither of these levels (44,200 and 40,500 mg/L) was a reduction relative to control. These levels were above the control by 14 to 23% representing an inability to reduce COD through habitat enhancement within the manure. Considering all of the additives' abilities to reduce COD none appeared to provide any substantial improvements. Even the 5% reduction produced by PB on Day 28 would likely be inconsequential considering the level was still 36,900 mg/L. This all suggests that the microbial habitat enhancement, chemical treatment and microbial and enzymatic augmentation provided by the additives were unable to increase utilization of manure components contributing to COD.

CONCLUSIONS

Three manure pit additives have been successfully tested in full-scale manure channels and simulated outdoor lagoons. The experimental design allowed the effectiveness of the additives in reducing odour threshold, gas and solids concentrations and maintenance of nutrients and micronutrients to be determined. It is believed that the results are representative of what can be obtained in a commercial operation because the experiment tests the additives under continuous manure addition by pigs with no artificial mixing of the manure.

Trial 1 results suggested that ABC was able to provide a 11 to 31% odour threshold reduction, PB was able to provide 16 to 66% odour threshold reduction and WB was able to provide a 2 to 37% odour threshold reduction. The 66% reduction in odour threshold produced by PB was the only significant reduction in the experiment. Combined indoor trial data indicated that the ABC and WB additives were only capable of reducing odour thresholds to a small degree (4 and 11%) on Day 35. Mean H_2S concentrations from the first trial indicated that all of the additives were capable of producing fairly large reductions in the range of 14 to 76% from Day 35 on. These reductions were at both high and low levels of control H_2S. Mean H_2S concentrations from both indoor trials indicated that none of the additives reduced H_2S on Day 28, but all reduced H_2S by

57 to 76% on Day 35. Regarding NH_3 concentrations in the combined indoor trials, all of the additives provided reductions. ABC produced the largest reduction on Day 35 (33%) and WB provided the most consistent reduction (18%).

In this experiment none of the additives produced practical reductions in TS that could have improved manure-handling ease. Likewise, the additives provided little or no solubilization above the levels observed in the control. The only indication of solubilization was with the WB product, but the amounts were fairly limited. ABC and WB produced total Volatile Solids reductions. The data appeared to indicate that the reductions produced by WB may have been via solubilization and by ABC via gas emissions. Overall, little benefit was observed regarding solids fractions in the manure.

Perhaps the strongest attribute of all of the additives was the ability to maintain levels nutrients and micronutrients above the control levels. ABC produced TKN levels 16 to 19% higher than the control for the entire experiment while slightly smaller benefits were produced by PB and WB on Day 35. The ability of the additives to maintain nitrogen in the available form, especially on Day 35 represents a potential of 9 to 25% more available nitrogen during field application. Likewise, the 4 to 23% more P in the manure relative to the control levels, promoted by the additives increases the nutrient value of the manure as a fertilizer. Of equal importance was the additives' ability to maintain ortho-phosphate levels above the control levels during the indoor trial. Improvements in the nutrient value were observed in the potassium results. ABC provided increases of 34%, WB of 17 to 21% and PB of 9 to 11%, relative to control levels. Another benefit that was observed was that additives increased levels of copper and zinc relative to the control. None of the additives were able to reduce COD levels relative to the control.

Overall, it appears that manure pit additives may provide some benefits to hog producers in all aspects except solids reductions and solubilization and waste strength reduction. However, the large variability within the results means that it will be difficult to firmly predict how additives will perform. To make progress in pit additive technology, more basic investigations are required to observe and understand the mode of action of additives on emissions from and characteristics of manure. Such understanding will likely allow for more control in the variability of manure pit additive effectiveness.

ACKNOWLEDGEMENTS

We would like to acknowledge the financial contribution of ADF that has allowed this much-needed research to be carried out. Similarly, the contributions of funding and product by American BioCatalysts, Chem-A-Co International Ltd. and Westbridge are greatly appreciated. Thanks must also be given to Sask Pork, Alberta Pork and Manitoba Pork for strategic funding contributed to the engineering research program at PSCI. Thanks must also be given to the University of Saskatchewan for their financial support in the form of a scholarship

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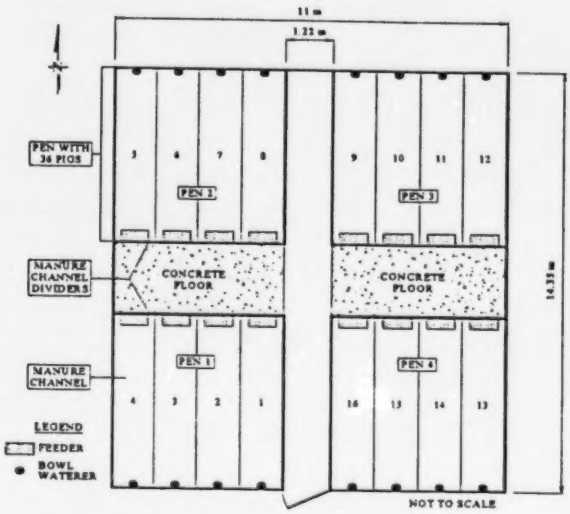

Figure 1. Sketch of the experimental room configured for the indoor manure channel experiment.

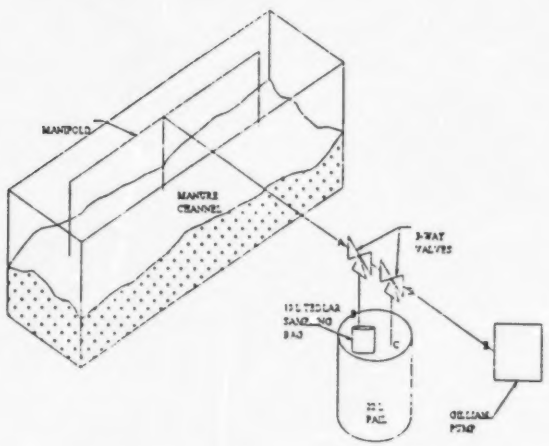

Figure 2. Sketch of indoor air sampling setup.

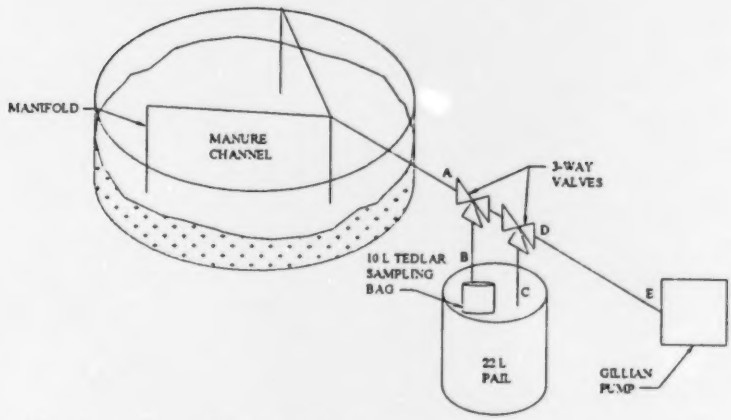

Figure 3. Sketch of outdoor air sampling setup.

Table 1. Means and percent differences from control means, for odour threshold (OU) and Hydrogen Sulphide (ppm) on Days 28, 35, 49 and 63 during Trial 1.

Component	Sampling Day	Treatment							
		Control		ABC		PB		WB	
		Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	Mean	% Diff.
Odour Threshold (OU) *	Day 28	1030 a	0	870 a	-16	1030 a	0	1010 a	-2
	Day 35	1010 a	0	900 a	-11	1250 a	24	1220 a	21
	Day 49	1010 a	0	1070 a	6	850 a	-16	920 a	-9
	Day 63	680 a	0	470 a	-31	230 b	-66	430 a	-37
Hydrogen Sulphide (ppm)	Day 28	0.63a	0	0.97 a	54	2.62 a	316	0.91 a	44
	Day 35	2.00 a	0	0.85 a	-58	0.48 a	-76	0.60 a	-70
	Day 49	9.38 a	0	4.03 a	-57	8.09 a	-14	3.13 a	-67
	Day 63	0.56 a	0	0.41 a	-27	0.37 a	-34	0.18 a	-68

Separation of means by row using LSD, $P>0.05$, $df = 15$

* statistics carried out on log transformations of odour threshold values

Table II. Combined means and percent differences from control means, for odour threshold (OU), Hydrogen Sulphide (ppm) and Ammonia (ppm) on Days 28 and 35 during indoor trials 1 and 2.

Component	Sampling Day	Treatment								LSD
		Control		ABC		PB		WB		
		Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	
Odour Threshold (OU)	Day 28	770 a	0	810 a	5	940 a	22	730 a	-5	*
	Day 35	1030 a	0	990 a	-4	1080 a	5	920 a	-11	*
Hydrogen Sulphide (ppm)	Day 28	0.44 a	0	0.70 a	57	1.35 a	205	0.56 a	25	0.9
	Day 35	1.19 a	0	0.51 a	-57	0.29 a	-76	0.38 a	-68	1.1
Ammonia (ppm)	Day 28	12.4 a	0	11.7 a	-6	11.8 a	-5	10.1 a	-18	8.6
	Day 35	14.9 a	0	9.9 a	-33	16.3 a	9	12.1 a	-19	6.8

Separation of means by row using LSD, $P>0.05$, $df = 31$

* statistics carried out on log transformations of odour threshold values

Table III. Combined means and percent differences from control means, for total solids, total suspended solids, total dissolved solids and total volatile solids on Days 28 and 35 during indoor trials 1 and 2.

Component	Sampling Day	Treatment								LSD
		Control		ABC		PB		WB		
		Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	
Total Solids (mg/L)	Day 28	43200 a	0	53600 a	24	39600 a	-8	49400 a	14	20600
	Day 35	37300 a	0	38600 a	4	42700 a	15	45300 a	21	16000
Total Suspended Solids (mg/L)	Day 28	28500 a	0	38400 a	35	15300 a	-46	41100 a	44	23900
	Day 35	33400 a	0	35000 a	5	34800 a	4	27000 a	-19	19400
Total Dissolved Solids (mg/L)	Day 28	9700 a	0	11800 a	22	8800 a	-9	9400 a	-3	3820
	Day 35	9000 a	0	13200 a	47	10300 a	14	12500 a	39	3780
Total Volatile Solids (mg/L)	Day 28	33900 a	0	41800 a	23	30500 a	-10	38600 a	14	16600
	Day 35	27800 a	0	27200 a	-2	33100 a	19	34200 a	23	13800

Separation of means by row using LSD, $P>0.05$, $df = 31$

Table IV. Combined means and percent differences from control means, for nutrients, micronutrient and chemical oxygen demand on Days 28 and 35 during indoor trials 1 and 2.

Component	Sampling Day	Treatment								LSD
		Control		ABC		PB		WB		
		Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	Mean	% Diff.	
TKN (mg/L)	Day 28	5270 a	0	6290 a	19	5290 a	0	5070 a	-4	1760
	Day 35	4970 a	0	5770 a	16	5590 a	13	5300 a	7	1480
Ammonium-nitrogen (mg/L)	Day 28	3350 a	0	3530 a	5	3200 a	-5	3350 a	0	809
	Day 35	3060 a	0	3820 a	25	3550 a	16	3330 a	9	858
Phosphorous (mg/L)	Day 28	2010 a	0	2130 a	6	2480 a	23	2210 a	10	1335
	Day 35	1190 a	0	1330 a	12	1280 a	8	1240 a	4	597
Ortho-Phosphate (mg/L)	Day 28	660 a	0	820 a	24	640 a	-3	810 a	23	374
	Day 35	453 a	0	531 a	17	527 a	16	560 a	24	286
Potassium (mg/L)	Day 28	2220 a	0	2970 a	34	2470 a	11	2690 a	21	734
	Day 35	2420 a	0	3240 b	34	2630 ab	9	2820 ab	17	746
Copper (mg/L)	Day 28	12.4 a	0	14.6 a	18	13.8 a	12	16.2 a	31	7.8
	Day 35	11.5 a	0	12.1 a	5	13.4 a	17	13.4 a	17	5.7
Zinc (mg/L)	Day 28	37.92 a	0	43.37 a	14	34.43 a	-9	45.30 a	20	25.5
	Day 35	35.93 a	0	36.60 a	2	37.00 a	3	38.19 a	6	19
COD (mg/L)	Day 28	38800 a	0	40400 a	4	36900 a	-5	44200 a	14	15495
	Day 35	33000 a	0	40000 a	21	41100 a	25	40500 a	23	15958

Separation of means by row using LSD, P>0.05, df = 31

June 22-25, 1999
Saskatoon, SK

Proceedings of a tri-provincial conference on manure management.

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Odour and gas concentrations from swine manure treated with pit additives in commercial scale manure channels and simulated outdoor storage

R. Stinson, Prairie Swine Centre Inc., Saskatoon;
S.P. Lemay; T. Fonstad; E.M. Barber

Abstract

A wide variety of manure pit additives are being used in hog production facilities to suppress odour and pit gas concentrations. The objective of this research was to measure the effectiveness of three manure pit additives (American BioCatalysts, Pit Boss and Westbridge (H4-502)) in reducing odour and gas concentrations in commercial scale manure channels and simulated outdoor lagoons. The indoor experiment was completed over two room turns in a room containing four pens, each of them positioned over four manure channels. The protocol consisted of three weeks of manure accumulation, two weeks of pretreatment and five weeks of treatment. Air samples were taken on Days 28 and 35 of the treatment phase. Effectiveness of additives was based on reduction in odour, NH_3, and H_2S concentrations in air samples taken just above the manure surface, under the slats, with a pulmonary pumping system. Odour concentrations were determined by forced choice dynamic olfactometry and gas concentrations were measured using colorimetric detection tubes. Comparisons of additives versus control were based on differences between means from eight replications. On Day 28, additives did not reduce odour, NH_3 or H_2S concentrations. On Day 35, additives reduced odour concentration above the manure in the range of 25 to 30%, NH_3 concentrations in the range of 19 to 33% and H_2S concentrations in the range of 57 to 76%. No statistical difference ($P>0.05$) between additive and control means was observed. Due to the variability of the measurements, the power of the experiment was relatively low, requiring differences in the range of 50% to be declared significantly different.

Following the first trial of the indoor experiment, the treated manure was transferred to simulated outdoor storage lagoons and the residual effect of the additives was evaluated in a randomized complete block design. The outdoor experiment consisted of four weeks of storage with air samples taken after four weeks (Day 63 of the entire experiment). On Day 63, additives reduced odour concentration by 48 to 81% and H_2S concentrations by 27 to 69%. American BioCatalysts additive produced the only significant ($P>0.05$) reduction in odour concentration relative to the control concentration. The power of the outdoor experiment was also quite low, contributing to the lack of significant reductions.

Introduction

Odour control is a primary concern for the swine industry because public perception of odour as a nuisance has given swine production a bad reputation. Proper

management practices, advances in manure injection techniques and storage lagoon covers have dissipated some of the concern. Yet, odour production still remains a fairly controversial topic. Another potential solution to odour concerns is manure pit additives, which are being produced commercially and are being used by many hog producers.

In the past, most of the evaluation of manure pit additives was not conducted independently of the manufacturer, so some question as to the validity of the results was present. As of late, more of the evaluations are being carried out by independent testing facilities, removing some of the doubt that may have been present in the past. Most of the testing has however, been carried out on a bench scale, which may not characterize the effectiveness of additives in barn applications. Many of the previous studies investigating the performance of manure pit additives have concluded with varying results.

Recent studies suggest that some improvements have been realized with the application of manure pit additives. In a study conducted by Zhu et al. (1997) all five additives tested (MPC, Bio-Safe, Shac, X-Stink and CPPD) reduced odour concentration by 58 to 87%, as determined through dynamic triangle forced-choice olfactometry,. Eight products (Bio Charge, Roebic Deod, Pit Boss, Shac, Bio-409, MS-4, Pit Stop and Deo Odorase) were evaluated in full-scale rooms, resulting in odour reductions of 5 to 48% and ammonia reductions of 42 to 51% (AURI 1997). Two (NX23 and BioSuper) of the five additives tested by Martinez et al. (1997) reduced NH_3 emissions by 40 to 50%. Heber et al. (1997) reported reductions of NH_3 emissions from 1.8 to 5.9 g/day-pig and small decreases in overall NH_3, H_2S and CO_2 concentrations. Out of the seven additives (Agri-Scents, Biosurge, Hydrogen cyanamide, Micro-Aid, Natural Odor Catalyst, Sphagnum peat and Roebic) evaluated by Patni and Jui (1993), five additives significantly reduced ammonia concentrations and three significantly reduced hydrogen sulphide concentrations. Successful application of acid treatments and sphagnum peat moss reduced losses of NH_3 by 74.6% (Al-Kanani 1992).

Many of these evaluations were carried out on a bench scale (Zhu et al. 1997; Patni and Jui 1993; Al-Kanani 1992), which may not represent actual commercial conditions adequately for testing purposes. It was suggested that manure additive testing should be performed in commercial scale manure channels as well as simulated outdoor storage. This experiment was designed to quantify a wide range of chemical characteristics in slurry and odour and gas concentrations in air. The objective of this research was to evaluate the effectiveness of three different kinds of manure pit additives to reduce odour, NH_3 and H_2S gas concentrations above the manure surface at four and five weeks of treatment in commercial manure pits, and after four weeks of storage in simulated lagoons. Data presented in this paper only represent measurements taken from air samples.

Materials and Methods

Experimental Design and Protocol

The indoor experiment was carried out in 16 manure channels located under four pens. For each block of four manure channels, each of the additives was applied in one of those

channels and a channel was kept as a control. Two indoor trials were conducted providing eight replications of each additive. In preparation for the experiment, the fully slatted room was power-washed, the manure channels were drained and power-washed, the slatted flooring was replaced and pens were constructed. A feeder and bowl waterer were positioned over each manure channel in each pen, to standardize feed and water wastage. Figure 1 is a sketch of the experimental room configuration.

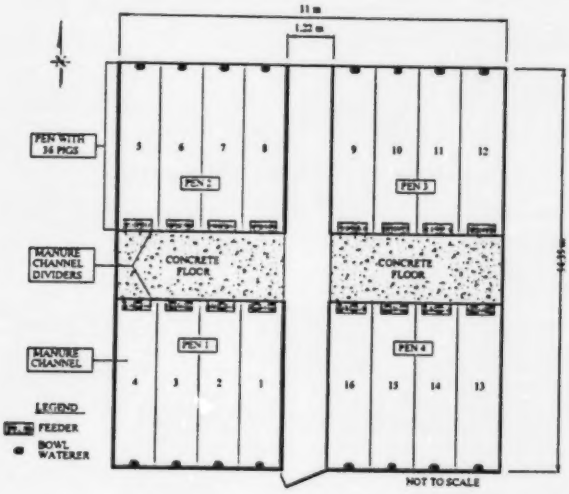

Figure 4. Sketch of the experimental room configured for the indoor manure channel experiment.

To begin the trials, 36 pigs with a mean weight of 20 kg were placed into each of the four pens and were fed *ad libitum* for the duration of the experiment. Each trial consisted of three phases: an accumulation phase, a conditioning phase and a treatment phase. The accumulation phase lasted for three weeks, where all of the manure that was produced was left untreated in the manure channels. In the following two weeks (conditioning phase) intended to simulate continuous barn operations, manure accumulated and was treated with the manure pit additives at recommended rates. At the end of the conditioning phase the manure channels were drained by gravity. Then, the manure accumulated and was treated at recommended rates for the next five weeks (treatment phase). At four and five weeks of the treatment phase (Day 28 and 35), air samples were collected above the manure surface. After the fifth week of the first indoor trial, manure was transferred to outdoor simulated lagoons to begin the outdoor trial.

The outdoor trial was conducted in 16 plastic containers simulating lagoons, situated in a staggered line, running west to east. The simulated lagoons were 1360 L (1.83 m diameter x 0.56 m high), heavy duty, black, plastic cattle waterers. In the outdoor experiment, manure was not treated after being transferred. The manure remained in the lagoon for four weeks (up to Day 63) and then air samples were taken above the manure surface in the same manner as the indoor samples were taken.

Additives

The additives that were evaluated in this experiment were American BioCatalysts (ABC), Pit Boss (PB) and Westbridge (WB). The ABC additive is a combination of enzymes and microbes intended to breakdown manure constituents both chemically and biochemically. PB is an acidified copper sulphate mixture, believed to react chemically and electrically with complex slurry components. The WB additive is an organic amendment intended to increase microbial activity and oxidize organic components of manure. Frequency and rates of additions used in the indoor experiment were as follows:

ABC: ABC 100E and preactivated ABC 200M at 1:100,000 on initial addition and 1:500,000 every two weeks.

PB: adjustment of manure pH to 7.0 then applied at 1:60,000 of final manure volume.

WB: applied at 1:100,000, based on daily manure production rates.

Air Sampling and Measurements

Air samples were taken with a pulmonary pumping system illustrated in Figure 2. Stainless steel quarter-inch tubing and stainless steel three-way valves were used in the manifold and tubing system to reduce interaction between the sampling system and the air sample. Samples were collected in 10 L Tedlar bags to provide a large enough volume for olfactometry measurements and to reduce interactions between the air sample and the bag. By using the pulmonary pumping system, the air sample did not come into contact with the Gilian AirCon-2 air sampler (Gilian Instrument Corp., W. Caldwell, NJ, USA).

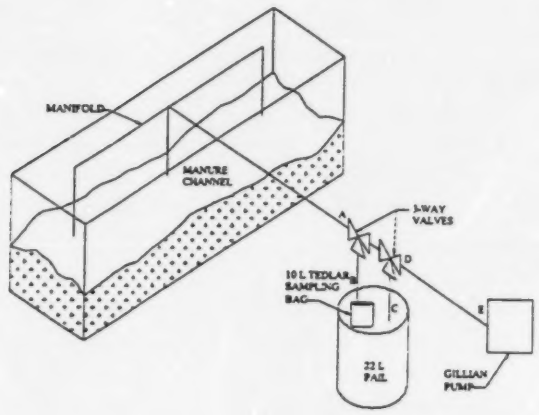

Figure 5. Sketch of indoor air sampling setup.

Before sampling, each manure channel was isolated by covering the surface with polyethylene secured to the flooring with 2x4 studs (indoor) and simulated lagoons were isolated with a sheet of plywood (outdoor). By isolating the manure, air samples would not be cross contaminated with air from outside the manure channel or simulated lagoon.

After isolating each manure channel or simulated lagoon, the manifold of the air sampling system was lowered to 5 cm above the surface of the manure in three locations. Before sampling, the line was purged for one minute at a flow rate of approximately 2 L/min. Then, the air sample was taken at a flow rate of approximately 2 L/min for 5 min. Two samples were taken from each manure channel, one for odour analysis and the other for gas concentration measurements.

Odour concentrations reported in odour units per cubic metre (o.u./m^3) were determined within 48 hours by forced-choice dynamic olfactometry at the Alberta Research Council in Vegreville, Alberta. Gas measurements reported in ppm were made with colorimetric detection tubes (Matheson Gas Products, Secaucus, NJ, USA).

Statistical Analyses

The indoor experimental design consisted of two trials (summer and fall, 1998) of a balanced 4x4 latin-square, with the two controlled effects: additive (n=4) and manure pit position in block (n=4). Additives were designated to manure channels such that each additive occurred in each pen once and also occupied each manure pit position once. The outdoor trial experimental design was a randomized complete block design.

All of the data were analyzed using the GLM procedure in SAS (Version 6.1 for Windows). Due to missing data, least-square means (LSMEANS) analysis was the most appropriate method for comparisons between additives. All comparisons between additive lsmeans were made using a pair-wise t-test (LSD) with a significance level of $P<0.05$.

Results and Discussion

Odour Concentration

Odour concentration measurements from Trial 1 and the combined indoor experiment (Trials 1 and 2) are presented in Table 1.

Table 3. Mean odour concentration and percent difference relative to control for trial 1 and combined indoor trials.

Additive	Odour Concentration (o.u./m^3)					
	Sampling Day 28		Sampling Day 35		Sampling Day 63	
	Lsmean	% Diff.	Lsmean	% Diff.	Lsmean	% Diff.
TRIAL 1						
Control	1070	0.0	1360	0.0	1240 a	0.0
ABC	890	-16.8	1060	-22.1	240 b	-80.6
PB	1080	0.9	1270	-6.6	590 ab	-52.4
WB	1080	0.9	1370	0.7	640 ab	-48.4
TRIALS 1 & 2	Lsmean (min; max)	% Diff.	Lsmean (min; max)	% Diff.		
Control	860 a (360; 1600)	0.0	1520 a (230; 3700)	0.0		
ABC	890 a (240; 1250)	3.5	1090 a (510; 1900)	-28.3		
PB	1060 a (220; 1850)	23.3	1120 a (730; 2100)	-26.3		
WB	820 a (290; 1700)	-4.7	1080 a (380; 2600)	-28.9		

Lsmean separation within columns by pair-wise t-test, P = 0.05, df = 15 (Day 63) and df = 31 (Combined data, Days 28 and 35)

LSDs for Trial 1 data are Day 63 (817) and Combined data on Day 28 (372), Day 35 (819)
% Diff. represents differences relative to control lsmean for additives

Differences between additive means in the first trial were only significantly different (P>0.05) on Day 63. The control mean was lowest on Day 28 (1070 o.u./m^3), peaking on Day 35 (1360 o.u./m^3) and falling to 1240 o.u./m^3 on Day 63. ABC additive was the most effective additive reducing the odour concentration relative to control on all three sampling days. The levels of 890, 1060 and 240 o.u./m^3 measured on Days 28, 35 and 63, respectively, were the lowest of any of the additives on any of these days. These odour reductions ranged from 16 to 81% lower than the control odour concentrations and the reduction on Day 63 was significantly different than the control. PB additive did not produce any drastic odour reductions (7% on Day 35) in the indoor portion of the trial, but produced a good reduction in the outdoor experiment (52%). WB additive also produced a good odour concentration reduction in the outdoor experiment (48%), but did not produce any reductions in the first indoor trial. In terms of the first indoor trial, ABC additive produced the best, overall, odour concentration reduction, while both PB and WB additives produced odour reductions in the outdoor experiment.

When data from both indoor trials are combined, differences between additive means are insignificant (P>0.05) and variations illustrated by minimum and maximum values are very large. Control odour concentration was lowest (860 o.u./m^3) on Day 28, when ABC (890 o.u./m^3) and WB (820 o.u./m^3) additives did not provide any substantial reduction in odour concentration. PB (1060 o.u./m^3) resulted in an odour concentration higher than the control. It is unlikely that small differences between ABC, WB and control additives represented either a beneficial or a detrimental effect. Whereas, the 23% increase in odour concentration produced by the PB additive represented a noticeable difference. PB odour measurements exhibited the largest variability (220, 1850) and none of the variability can be explained by the measurements or any experimental problem or deviation. On Day 35, control odour concentration nearly doubled from the Day 28 concentration to 1520 o.u./m^3. At the same time, all three additives produced limited increases in odour concentration. The activity of the additives resulted in reductions of 26 to 29% in relation to control odour concentration. Although these reductions are not significantly different from the control odour concentration, they represented improvements in regards to odour emissions. Therefore, it was only on Day 35 that the additives produced some benefits in the form of odour concentration reductions.

In comparing odour concentrations with gas and solids concentrations from this experiment, no strong correlations were found that could indicate that changes in gas or solids concentrations resulting from treatment had an effect on odour concentration.

Ammonia Concentration

Ammonia concentration measurements from trial 1 and the combined indoor experiment (Trials 1 and 2) are presented in Table 2. Control NH_3 concentrations in trial 1 displayed a decreasing trend for the duration of the experiment. The ABC additive was successful in reducing NH_3 concentrations by 17 to 47% in the indoor portion of the trial,

but the NH_3 concentration was very high relative to control on Day 63. The same success was observed with PB, except that the reductions were lower (5 to 29%) in the indoor phase. In the outdoor phase, PB performed better than ABC, limiting the NH_3 increase relative to control to 27%. WB additive was the only completely successful additive in trial 1. It maintained NH_3 levels below control levels for the entire experiment, reducing the level by 8 to 55%. In trial 1, it is clear that the WB additive provided the best and most consistent NH_3 reduction.

Combined data from the two indoor trials indicated no significant ($P>0.05$) differences between additive means and large variations between minimum and maximum values. Control concentrations of NH_3 were 12.4 and 14.9 ppm. ABC additive produced a slight reduction (5.7%) in NH_3 concentration on Day 28 and a 33% reduction on Day 35. PB also produced a slight reduction (4.6%) in NH_3 concentration on Day 28, but failed to result in a reduction on Day 35. These reductions produced by PB were much lower than the reductions of approximately 50% reported by AURI (1997). WB additive provided reductions of approximately 18% on both sampling days. Overall, ABC produced the best NH_3 concentration reduction on Day 35 but WB produced the most consistent reductions.

Table 4. Mean ammonia concentration and percent difference relative to control for trial 1 and combined indoor trials.

Additive	Ammonia (ppm)					
	Sampling Day 28		Sampling Day 35		Sampling Day 63	
	Lsmean	% Diff.	Lsmean	% Diff.	Lsmean	% Diff.
TRIAL 1						
Control	18.9	0.0	16.8	0.0	5.0 a	0.0
ABC	15.7	-16.9	8.9	-47.0	10.7 a	113.1
PB	13.4	-29.1	16.0	-4.8	6.3 a	26.9
WB	8.5	-55.0	12.9	-23.2	4.6 a	-7.5
TRIALS 1 & 2	Lsmean (min; max)	% Diff.	Lsmean (min; max)	% Diff.		
Control	12.4 a (2.0; 37.5)	0.0	14.9 a (2.5; 32.5)	0.0		
ABC	11.7 a (1.0; 23.0)	-5.7	9.9 a (2.3; 19.0)	-33.4		
PB	11.8 a (3.5; 16.5)	-4.6	16.3 a (5.5; 30.0)	9.3		
WB	10.1 a (2.0; 25.0)	-18.2	12.1 a (5.0; 21.0)	-18.9		

Lsmean separation within columns by pair-wise t-test, P = 0.05, df = 15 (Day 63) and df = 31 (Combined data, Days 28 and 35)
LSDs for Trial 1 data, Day 63 (6.8) and Combined data, Day 28 (8.6), Day 35 (6.8)
% Diff. represents differences relative to control lsmean for additives

Hydrogen Sulphide Concentration

Table 3 illustrates hydrogen sulphide concentration measurements from trial 1 and the combined indoor experiment (Trials 1 and 2).

Table 5. Mean hydrogen sulphide concentration and percent difference relative to control for trial 1 and combined indoor trials.

Additive	Hydrogen Sulphide (ppm)					
	Sampling Day 28		Sampling Day 35		Sampling Day 63	
	Lsmean	% Diff.	Lsmean	% Diff.	Lsmean	% Diff.
TRIAL 1						
Control	0.63	0.0	2.00	0.0	0.56 a	0.0
ABC	0.97	54.0	0.85	-57.3	0.41 a	-27.2
PB	2.62	315.9	0.48	-76.0	0.37 a	-35.0
WB	0.91	44.8	0.60	-70.0	0.18 a	-68.9
TRIALS 1 & 2	Lsmean (min; max)	% Diff.	Lsmean (min; max)	% Diff.		
Control	0.44 a (0.1; 1.1)	0.0	1.19 a (0.1; 6.0)	0.0		
ABC	0.70 a (0.0; 1.3)	56.7	0.51 a (0.4; 2.0)	-57.3		
PB	1.35 a (0.1; 6.0)	205.0	0.29 a (0.1; 1.5)	-75.9		
WB	0.56 a (0.1; 1.5)	25.4	0.38 a (0.1; 1.5)	-67.9		

Lsmean separation within columns by pair-wise t-test, P = 0.05, df = 15 (Day 63) and df = 31 (Combined data, Days 28 and 35)
LSDs for Trial 1 data, Day 63 (0.6) and Combined data, Day 28 (0.9), Day 35 (1.1)
% Diff. represents differences relative to control lsmean for additives

Data from trial 1 suggest that none of the additives were able to reduce H_2S concentrations relative to control on Day 28, but by Day 35, all of the additives produced good reductions. The reductions ranged from 57 to 76% and were followed by slightly smaller reductions on Day 63. The best reduction was produced by WB (69%), followed by PB (35%) and ABC (27%). Overall, all of these reductions are fairly substantial on Days 35 and 63, but in general the levels are also very low compared to the colorimetric tube detection limit.

Means from the combined indoor trials illustrates the same findings as trial 1 means. The variation in concentrations indicated by the minimum and maximum values are quite large, but large variations in H_2S concentration are consistent with large variations observed in odour and NH_3 concentrations. On Day 28, none of the additives were able to reduce the H_2S concentration relative to control. Then on Day 35, all of the additives reduced H_2S in the range of 57 to 76%, representing substantial reductions.

Conclusions

Three kinds of manure pit additives have been successfully tested in full scale manure channels and simulated outdoor lagoons. The experimental design allowed the measurement of the effectiveness of the additives in reducing odour, ammonia and hydrogen sulphide concentrations. It is believed that the results are representative of what can be obtained in a commercial operation because the experiment tests the additives under continuous manure addition by pigs with no artificial mixing of the manure.

Trial 1 results suggested that ABC was able to provide a 17 to 81% odour concentration reduction for the entire experiment and that all additives could produce odour reductions (48 to 81%) in the outdoor storage phase. Combined indoor trial data indicated that the additives were only capable of reducing odour concentration to any

discernable level (26 to 29%) on Day 35. Regarding NH_3 levels in trial 1, only WB additive produced ammonia suppression for the entire experiment (8 to 55%). Combined indoor trial data seems to indicate that the reductions produced by all of the additives in the first trial (5 to 55%) may be larger than mean reductions (5 to 33%). Mean H_2S concentrations from both trials indicated that none of the additives reduced H_2S on Day 28, but reduced H_2S on both other sampling days. On Days 35 and 63, both sets of results indicated reductions of 57 to 76% and 27 to 69% on Days 35 and 63, respectively.

Overall, it appears that manure pit additives may provide some benefits to hog producers in terms of odour and ammonia concentration reductions. However, the large variability within the results means that it will be difficult to firmly predict how additives will perform. To make good progress in additive technology, more basic investigation will be required to observe and understand the mode of action of additives on emissions and characteristics of manure pit gas. Such understanding will likely allow for more control in the variability of manure pit additive effectiveness.

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A method for evaluating manure pit additives in manure channels and simulated outdoor lagoons

R. Stinson[1], S.P. Lemay[1], T. Fonstad[2] and E.M. Barber[2]

[1] Prairie Swine Centre Inc., P.O. Box 21057, 2105 - 8th St. East, Saskatoon, SK. S7H 5N9 and [2] Department of Agricultural & Bioresource Engineering, University of Saskatchewan, Saskatoon, SK. S7N 5A9

Odour complaints and manure handling issues are influencing many pork producers to reconsider their manure management practices. Some of the desired improvements regarding manure management include reducing odours, reducing and solubilizing solids, retaining nutrients, suppressing gas production and limiting the addition of heavy metals through spreading on land. To attain these improvements, many producers have opted for the use of manure pit additives in their facilities, although the effectiveness of these treatments is still in question. The objective of the methodology is to determine the effectiveness of manure pit additives on a commercial scale in underfloor manure channels and on a reduced scale in simulated outdoor storage lagoons. The testing is completed in a full-scale commercial room with four individual manure channels per pen. Manure is accumulated and pretreated to simulate continuous barn activity. Then the manure is treated with the manure pit additive for the actual testing period. Treatments are evaluated over two trials, providing eight replicates of each treatment. Slurry and air samples are taken after four and five weeks of treatment during the indoor trial and seven and nine weeks in the following outdoor trial. To evaluate the treatments' performance, a number of parameters are determined. Nitrogen, phosphorous and potassium levels are determined to evaluate nutrient content. Total solids, total suspended solids and total dissolved solids are measured to indicate reduction and solubilization of solids. Heavy metal levels that are determined include arsenic, copper and lead. Air samples are evaluated for odour concentration by forced-choice dynamic olfactometry. In addition, ammonia, hydrogen sulphide and carbon dioxide concentrations are also measured. Following the indoor trial, treated manure is transferred to simulated outdoor lagoons to determine if the treatment has a residual effect.

Implication

This methodology provides results that are representative of full-scale treatment of manure channels with manure pit additives. The resulting information will allow both producers and regulators to determine if manure pit additives are capable of producing the desired results.

Advances in Pork Production (1999) Volume 10, Abstract #21

Evaluation of Three Additives in Manure Channels and Simulated Outdoor Lagoons (In Progress)

R. Stinson[1], S.P. Lemay[1], T. Fonstad[2] and E.M. Barber[2]

[1] Prairie Swine Centre Inc., P.O. Box 21057, 2105 - 8th St. East, Saskatoon, Saskatchewan, CANADA, S7H 5N9
[2] Department of Agricultural & Bioresource Engineering, University of Saskatchewan, Saskatoon, Saskatchewan, CANADA S7N 5A9

Abstract

Odour complaints and manure handling issues are influencing many pork producers to reconsider their manure management practices. To attain these improvements, many producers have opted for the use of manure pit additives in their facilities, although the effectiveness of these treatments is still in question. The objective of the following methodology is to determine the effectiveness of manure pit additives on a commercial scale in underfloor manure channels, and on a reduced scale in simulated outdoor storage lagoons. The criteria for evaluation were odour concentration reduction, gas suppression, solids reduction/solubilization and nnitrogen retention. The experimental design for the manure channel experiment was a Latin-square design consisting of four individual manure channels beneath each of four pens. Manure was accumulated and pretreated to simulate continuous barn activity, then the manure was treated with the manure pit additive for the actual testing period. The treatments that were tested include American BioCatalysts, Pit Boss and Westbridge (H4-5O2). Treatments were evaluated over two trials, providing eight replicates of each treatment. Slurry and air samples are taken at four and five weeks of treatment during the indoor trial and two and four weeks in the following outdoor trial. The outdoor trial utilized a randomized complete block design.

The results presented in this poster summarize the preliminary odour and gas concentration measurements, solids reduction and solubilization and nitrogen conservation. It seems that the treatments did provide some benefits, in both

phases of the experiment (indoor and outdoor) but none of the treatments appears to have been successful in all aspects throughout the entire experiment.

Introduction

According to municipalities, government agencies, environmentalists and the public in general, manure management is one of the main issues that the pig industry needs to address in order to sustain its development. Two important areas for manure management that occur in livestock facilities are underfloor manure channels and outdoor storage. Manure pit additives may represent a viable method for controlling odour production during these phases of manure storage. In addition to odour control, manure pit additives are claimed to reduce nutrient loss and pit gas production, and increase the breakdown/liquefaction of solids. Reductions in odour emissions will allow hog production facilities to be a more welcome addition to their community. Suppressing gas production (NH_3 and H_2S) will reduce animal and worker health concerns. Reducing and solubilizing solids will improve the overall ease of manure handling and nitrogen retention will allow the manure to be a more valuable resource in the agriculture industry. If manure pit additives are able to provide these benefits, hog production units would be more socially and environmentally acceptable.

To the best of our knowledge, no controlled barn scale measurements on pit additives in manure channels or the storage phase have been conducted in Canada. Therefore, the swine industry has not been provided with an unbiased recommendation regarding pit additives. This independent study on pit additives simulating commercial conditions will provide the necessary information for Canadian producers to make educated decisions on manure pit additive use.

Objectives

- To measure physical and chemical characteristics of swine manure treated with three manure pit additives, in commercial scale manure channels and simulated outdoor lagoons.
- To evaluate odour and gas emissions from swine manure treated with three manure pit additives, in commercial scale manure channels and simulated outdoor lagoons.

Methodology

➢The Treatments

The three manure pit additives that were tested were American BioCatalysts (ABC 100E and ABC 200M), Chem-A-Co International Ltd. (Pit Boss) and Westbridge (H5-4O2). The ABC treatment is a biological product utilizing facultative anaerobic bacteria together with enzymes, Pit Boss is a copper-based product designed to function as an anti-biotic/disinfectant and Westbridge is a habitat enhancer.

➢Indoor Manure Channel Experiment

The indoor manure channel experiment is a Latin-square design, with treatment (ABC, Pit Boss, Westbridge and Control) and dunging gradient being controlled. The manure channel was the experimental unit. Four replications of each treatment were made over two room turns, for a total of eight replications per treatment. Manure was supplied for the experiment by 36 pigs per pen, located over four manure channels. The pigs were fed and watered *ad libitum*.

To begin the experiment, a three-week accumulation of manure was treated with the manure pit additives. These pit additives were allowed to operate for the following two weeks and then the manure channels were emptied. This helped to simulate long-term pit treatment by conditioning the manure channels before the treatment phase. Following the pretreatment phase, the manure channels were treated for five weeks with the additives as recommended by the supplier. On days 28 and 35 of the treatment phase, air and slurry samples were taken to allow measurements to be made. The resulting data were used to evaluate the effectiveness of the additives. This procedure was carried out two times, resulting in eight replications of each additive.

➢Outdoor Simulated Lagoon Experiment

After the first replicate of the indoor phase of the experiment, approximately 2,250 L of the treated manure was transferred from the manure channels into simulated outdoor storage outside of the barn. The experimental design was a partially randomized complete block, with the simulated lagoon being the experimental unit. In the outdoor phase, there were only four replications per treatment, because this phase of the experiment was repeated only once

under warm summer conditions when odour is more of a concern. The treatments were evaluated using air samples taken on day 14 and air and slurry samples taken on day 28 of the outdoor trial.

Air and Slurry Sample Analyses

Odour samples were taken using a pulmonary pumping technique and a stainless steel manifold. The odour samples were sent to the Alberta Research Council's dynamic olfactometry lab, which uses an eight-member odour panel for analysis. A resulting odour concentration is determined. Gas concentrations were measured from another set of air samples taken at the same time as odour samples. The gases measured were NH_3 and H_2S. Gas concentrations were determined with a hand held pump and colorimetric tubes.

Slurry samples were taken from three locations in the manure channel and then a composite sample was created before evaluation. The parameters representing nitrogen content that were measured include total kjeldahl nitrogen (total nitrogen) and ammonium nitrogen (available nitrogen). To determine if solids were being reduced or liquefied, the slurry was evaluated for total solids (TS), total dissolved solids (TDS) and total suspended solids (TSS).

RESULTS AND DISCUSSION

➢Odour Reduction

Figure 1demonstrates the mean arithmetic and geometric odour concentration of each treatment determined by an odour panel using forced-choice dynamic olfactometry. Results are presented for both the indoor manure channel and outdoor simulated lagoon experiment.

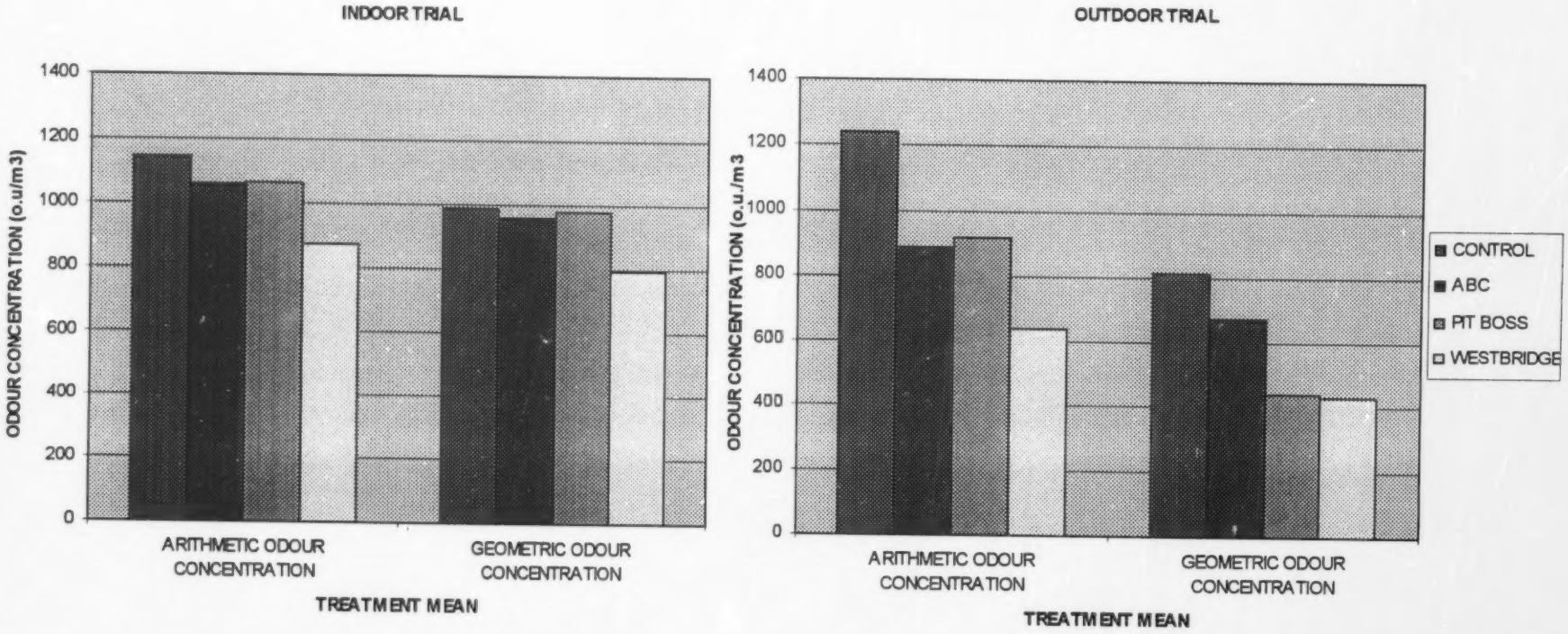

Figure 1. Mean arithmetic and geometric odour concentrations of manure treated with pit additives, determined by forced-choice dynamic olfactometry, carried out on air samples taken in both indoor and outdoor trials.

It appears that all of the products provided a decrease in arithmetic and geometric odour concentration in comparison with the control. In both the indoor and outdoor trials, Westbridge provided the best odour concentration reduction followed by ABC and Pit Boss.

➢ H_2S and NH_3 Gas Reduction

Figure 2 combines the resulting gas concentrations determined during both the indoor and outdoor trials.

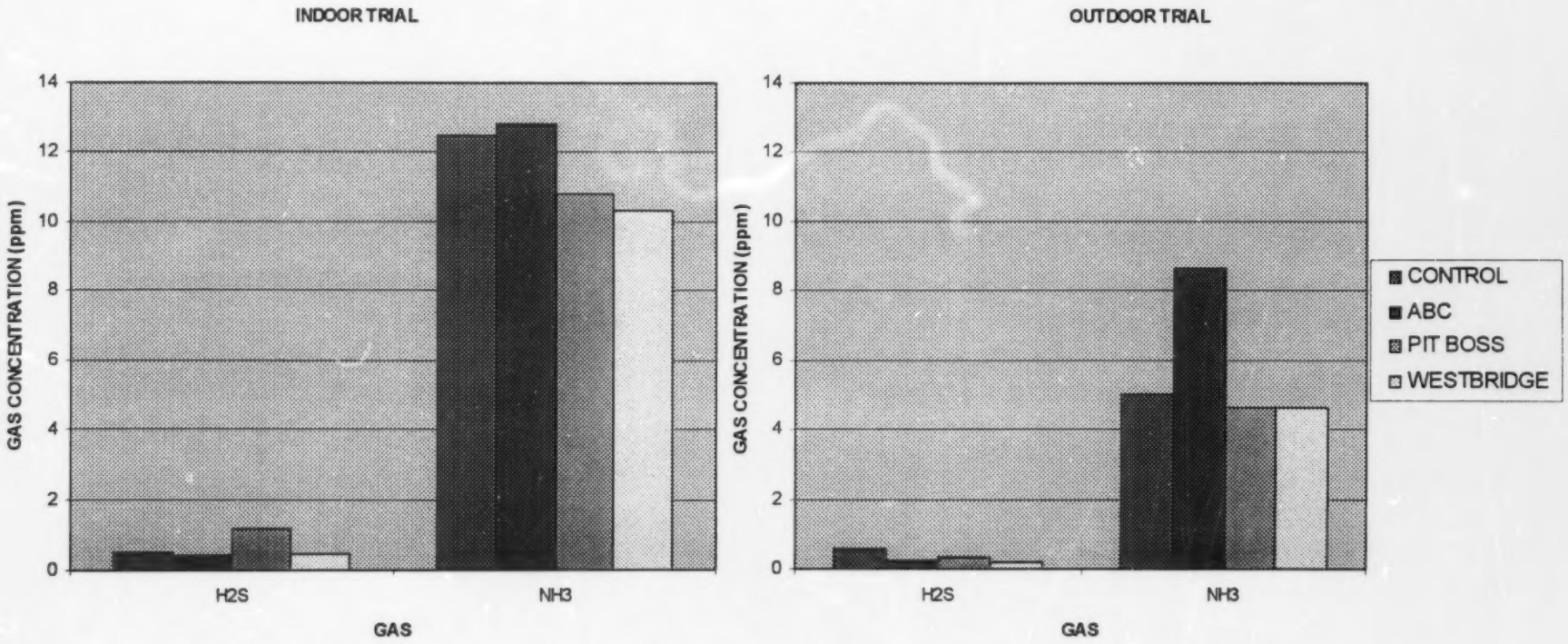

Figure 2. Mean hydrogen sulphide and ammonia gas concentrations measured in the indoor and outdoor trials, emitted from manure treated with pit additives.

In regards to gas suppression, using the control treatment as a baseline, ABC reduced the H_2S concentration in both trials but was ineffective in reducing NH_3 concentrations. Pit Boss reduced the NH_3 concentration in the indoor trial and both gas concentrations in the outdoor trial. Westbridge reduced both gas concentrations in both of the trials.

➢Solids Reduction and Liquefaction

Figure 3 illustrates the average total solids (TS), total suspended solids (TSS) and total dissolved solids (TDS) determined for each treatment in both of the trials.

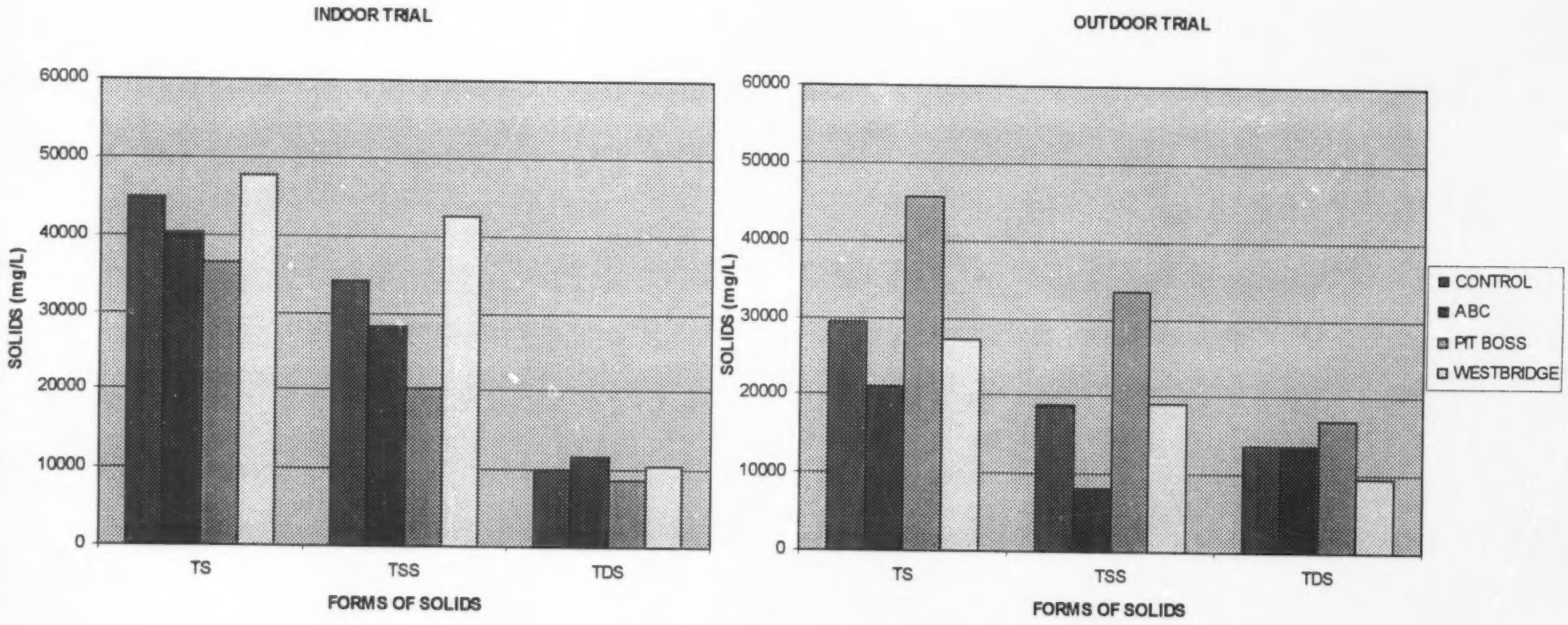

Figure 3. Mean total solids (TS), total suspended solids (TSS) and total dissolved solids (TDS) levels, indicating solids reduction and liquefaction in manure treated with pit additives.

In terms of total solids, ABC and Westbridge provided the best solids reduction respectively while Pit Boss failed to reduce the amount of solids. Regarding solids liquefaction, ABC provided a decrease in TSS in combination with an increase in TDS. Both of the other treatments did not exhibit this liquefaction trend.

➢Nitrogen Retention

Both total nitrogen and available nitrogen levels were determined. Figure 4 summarizes the resulting data for both of the trials.

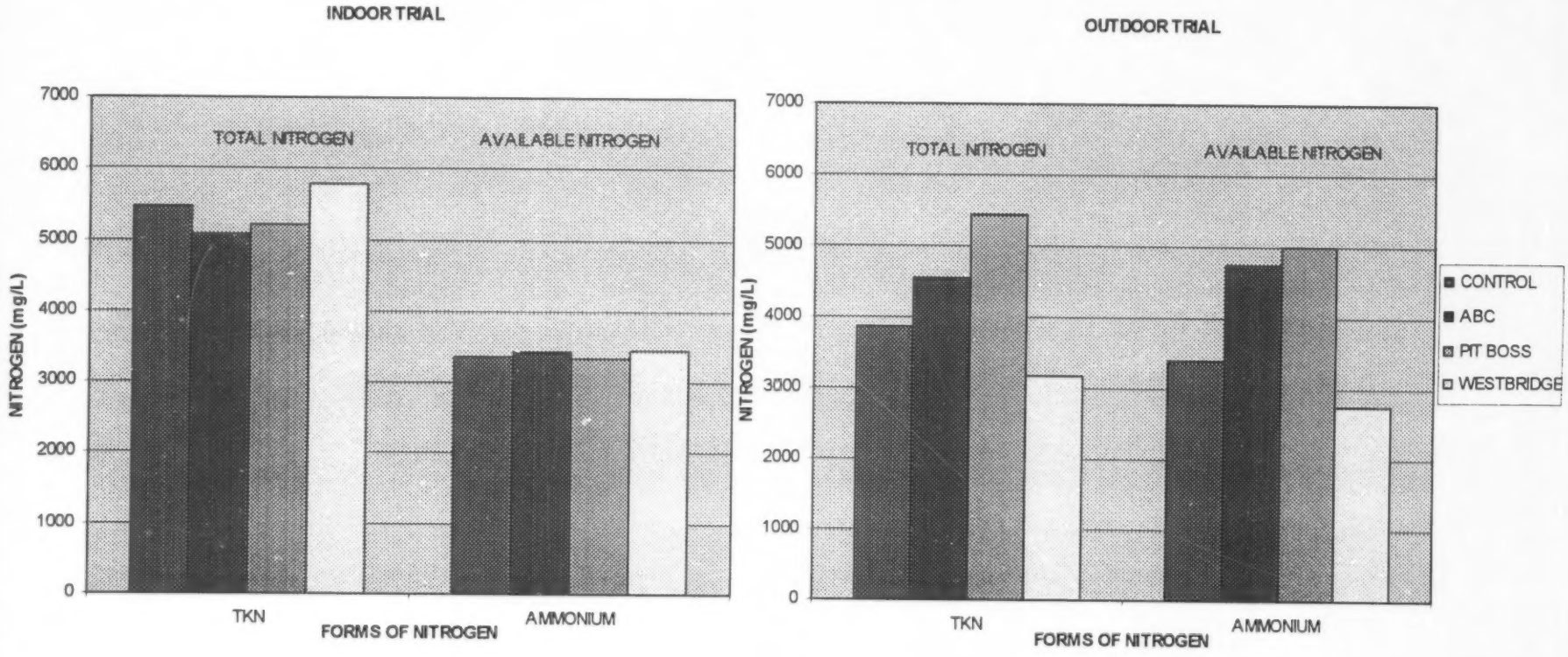

Figure 4. Mean total Kjehldahl nitrogen and ammonium-nitrogen concentrations, illustrating nitrogen retention and availability in manure treated with pit additives.

In the indoor trial, all of the treatments appeared to provide the same degree of nitrogen retention as the control. The same claim can be made regarding available nitrogen, with Westbridge providing the best results, although all appear to have retained the majority of the nitrogen in an available form. In the outdoor trial, Pit Boss and ABC provided the best overall retention and nitrogen availability and Westbridge exhibited losses with respect to both parameters.

CONCLUSIONS

Without having all of the statistical evaluation completed, firm conclusions can not be drawn on the effectiveness of any of the three treatments at this point in time. It does appear that all of the treatments do provide some form of benefit when applied. But, no one treatment seems to provide benefits in all aspects including odour concentration reduction, gas reduction, solids reduction/liquefaction and nitrogen retention in both of the trials. These results represent the effectiveness of the pit additives on a commercial scale, which provides important evidence to both producers and regulators.

ACKNOWLEDGEMENTS

We would like to acknowledge the financial contribution of ADF that has allowed this much-needed research to be carried out. Similarly, the contributions of monies and product by American BioCatalysts, Chem-A-Co International Ltd. and Westbridge are greatly appreciated. Thanks must also be given to APPDC for their contributions to PSCI and especially the engineering research department that provides the infrastructure for this and other engineering experiments to take place.